ENERGY AND MATTER

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ENERGY AND MATTER

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TO MY WIFE

WHO SHARED IN THIS

WORK

'*Modern physics is in a state of confinement; it is giving birth to dialectic materialism.*'—LENIN.

'*With each epoch-making discovery in the sphere of natural science, materialism has to change its form.*'—ENGELS.

'*The practice of advancing general principles and applying them to particular instances is so far from being fatal to truth in all the sciences, that when those principles are advanced on sufficient grounds, it constitutes the essence of true philosophy.*'

—THOMAS YOUNG.

CONTENTS

INTRODUCTION

SCIENCE is creating a revolution in human thought. Old ideas about the world we live in are crumbling. Major scientific discoveries are altering the outlook of millions of people.

The science which is foremost at present in bringing about this revolution in human thought is physics. Though most physicists are singularly innocent concerning the social aspects of their science, their discoveries are having profound social effects – political, military and philosophical.

Particularly important is the coming change in the general concept of matter now being introduced by the facts of physics. Matter – branded up till now as purely inert – is forcing upon physics a recognition of its active aspect.

Physicists, however, are loth to discard the basic premisses upon which their science still rests. Unwilling to admit that matter is active as well as passive, they hold to the obsolete idea that all physical change is due to 'something' non-material – something that was once called 'force', and is now known as energy. Energy is thus contrasted to allegedly inert matter.

We can eliminate this false contrast between energy and matter through an understanding of dialectic materialism, the philosophy which is a science of the sciences. Examining the facts of physics in the light of dialectic materialism, we realize that energy is the quantitative aspect of a universal quality of matter, namely motivity.

Casting off the bad philosophy with which physics is still saddled, we can use the facts of that science to give us a new world outlook, far richer than anything hitherto imagined in scientific circles. In that world outlook, matter scintillates with an infinite variety of qualities – of overlapping states, interpenetrating processes, dynamic forms and conflicting tendencies.

Dialectic materialism shows matter to be self-motivated, capable *per se* of every kind of change, including the changes that bring order out of disorder. What was once attributed to the guiding hand of a supernatural agency is now seen to proceed from fundamental characteristics of matter in motion.

The formation of a crystal, with its constant and characteristic order of atomic arrangement; the growth of a living organism, with its minutely regulated flow of metabolic constituents; the vast cosmic order of rotating nebulae, spinning stars, revolving planets – such are signs that for matter in general as for human individuals, 'character is fate'.

Destiny is the dynamic interplay of material tendencies. It is our human understanding of this which lifts us above the automatic operation of laws of nature. Our knowledge of natural law enables us to estimate and modify the course of events. 'Freedom is the recognition of necessity.'

Scientific truth is knowledge which gives us the power to regulate the motion of matter, and thereby to direct our own destiny. Such truth is modified, widened and deepened as science advances.

In physics, however, where various obsolete assumptions are hopelessly inadequate for constructive thinking, the word truth is now practically taboo. In order to avoid an open and drastic revision of their basic assumptions, physicists commonly take up the philosophical standpoint of pragmatism. This philosophy – the last ditch of resistance to modern materialism – banishes the concept of truth, and installs in its place a myopic adherence to immediate practical requirements.

The criterion of practice, as a means of determining the truth of an idea, is thus debased to a level of mere personal convenience. Denying that scientific truth is essentially an approximation of theory to physical reality, physicists commonly maintain that truth is merely what is useful in practice to themselves. The highest truth is then the most convenient or effective means of making a piece of laboratory apparatus – or an atomic bomb.

Questioned about the fundamental nature of energy, space and time, physicists usually evade the question by branding it as 'philosophical'. A favourite alibi for ignorance on fundamental issues of science is this bald statement that such issues are philosophical, and therefore beyond the scope of science.

To obtain a physics degree, undergraduates will one day be obliged to take courses in epistemology, semantics, the history of science, and the theory of measurement. For all these subjects enter the science of physics.

Epistemology – the systematic study of the grounds of our

knowledge – was given a materialist expression by three scientists, Einstein, Podolsky and Rosen, when they wrote:

'Any serious consideration of a physical theory must take into account the distinction between the objective reality, which is independent of any theory, and the physical concepts with which the theory operates. The concepts are intended to correspond with the physical reality, and by means of these concepts we picture this reality to ourselves . . . the correctness of the theory is judged by the degree of agreement between the conclusions of the theory and human experience. This experience . . . in physics takes the form of experiment and measurement' (*Physical Review*, 1935).

Semantics – the systematic study of words and their meanings – teaches us to avoid the futile type of argument which comes from a failure to define what we are talking about. Much pointless discussion, for instance, can be avoided by defining what is meant by the term *matter*.

Theoretical physics embodies the premiss that matter consists of discontinuous parts (particles) which are absolutely discrete. Dialectic materialism makes no such assumption concerning the fundamental structure of matter. From the standpoint of modern materialism, *matter is that which exists independently of thought*. Matter is a complex of physical processes which is real in the sense that it exists independently of our ideas about it.

The ideas of science do not fall from the sky, nor do they arise from observation alone; they develop through observations and experiments from previous ideas. The great experimental discoveries of science have been promoted by the dialectical development of scientific thought. *Du choc des idées jaillit la lumière*.

Hence the importance of the history of science. Only by tracing the historical development of physics can we grasp fully the basic concepts of that science, including the concepts of matter and energy.

What is energy? To answer this question satisfactorily, we must draw upon the theory of measurement, as well as upon the history of science. Or rather – since the theory of measurement is at present in a pitiful state of disrepair – we must create an adequate theory of measurement.

For seven years, a committee of the British Association for the Advancement of Science, appointed in 1932, debated the problem of measurement. In particular, the committee tried to decide whether it is possible to measure human sensation. This deliberation, comments S. S. Stevens, Director of the Psycho-Acoustic Laboratory of Harvard University, 'led only to disagreement, mainly about what is meant by the term measurement'.

The best way out of this difficulty is to see what is actually done in making a measurement. A measurement is in fact a comparison between a particular quantity and another quantity chosen as a standard. The standard quantity is reckoned as a unit, and the quantity being measured can then be defined numerically in terms of that unit.

Measurement, as distinct from counting, consists of comparisons which give numerical definitions of quantities.

Any physical quantity, however, is a quantity *of something, or of some physical quality.* A bushel is a quantity of grain. A poise is a quantity of viscosity. A gram is a quantity of inertia, and so on.

Some physicists have lost sight of this fact. H. Weyl, for example, in his *Space, Time, Matter*, refers to 'the constructive mathematical method of our modern physics, which repudiates "qualities"!'

Such an attitude can only be compared to a painter who repudiates pigments, or a captain who repudiates the sea. The fact is, physicists are perpetually dealing with physical qualities, which are modes of existence or modes of behaviour of matter.

A physical quality is a state, a form, a process or a tendency of matter. The *state* of translatory motion, the circular *form* of a wheel, the *process* of electric conduction – these are physical qualities. Another example of a physical quality is elasticity – the *tendency* of a body to regain its original shape after deformation.

While quantitative differences are subject to measurement or to counting, qualitative differences are not. The essential difference between cabbages and kings can be perceived and described in words, but cannot very well be defined in numbers by means of measurement.

For a scientific approach to the study of physical qualities,

we must turn to dialectic materialism – the philosophy that is a method as well as a world outlook.

Dialectic materialism is philosophy that formulates the most general laws of nature – and the very special part of nature that is human society. Dialectic materialism is a method of approach to particular problems, the various sides of which are considered in conjunction with one another. This many-sided view of things helps to blend together the different pictures of physical reality provided by the different sciences.

Dialectic materialism also links the various sciences together by formulating the most general laws of nature. By reason of their general character, these formulations – the principles of materialist dialectics – belong to all the sciences. Modern materialism is thus a science of the sciences.

The principles of dialectic materialism are not a dogma to be imposed on science; they are derived, like any theory of a particular science, from observations, and can be confirmed by scientific experiments.

The dialectic principle that quantitative change sooner or later produces qualitative change is now familiar to many experimentalists. Less familiar perhaps is the dialectic principle applied throughout the present work – the principle that matter consists of conflicting physical qualities that interpenetrate one another, and by their mutual opposition give rise to irreversible physical change.

In the present work, the principles of dialectic materialism are employed to clarify and advance our knowledge of space, time, mass and energy. And since these quantities are dealt with specifically by physics, we are obliged to invade the theoretical domain of that science.

Since at least two of the founders of theoretical physics were medical men, the author has an excellent precedent for this invasion. But no such precedent is needed. No science can exclude a materialist inspection of its basic assumptions and main conclusions. Modern materialism is a science of the sciences, not an esoteric philosophy which stands apart from the facts and figures of scientific data.

Our invasion of physics has a definite purpose. That purpose is to close the gap between physics and common sense; between

the basic theory of physics and the perceptual information available through the ordinary use of our senses.

At the present time, the conceptual picture of physical reality provided by physics is very different to the picture provided by sensory perception – so different that the majority of people are unable to reconcile these two views of the physical world. Yet physics simply provides new insight into the same physical qualities that play upon our senses, and give us our ordinary perceptual pictures of the physical world. Those qualities are extension, motion, inertia and motivity – four universal modes of existence of matter.

In the light of modern materialism, space, time, mass and energy are seen to be the quantitative aspects of four mutually related modes of existence of matter – extension, motion, inertia and motivity. To grasp this truth is to hold a key that unlocks many doors.

Chapter I

MATTER, ENERGY AND ETHER IN NEWTONIAN PHYSICS

1. Matter

In the first half of the nineteenth century, Newtonian mechanics and early atomic theory presented an extremely simple picture of the physical world, which was held to consist fundamentally of discrete material bodies, imponderable forces and empty space, all existing in an independent 'flow' of time. Matter was thought to consist only of indivisible particles, aggregations of which formed larger bodies. Matter was regarded as fundamentally homogeneous and inert, its various changes being attributed to the action of different 'forces' – impressed, elastic, thermal etc.

The main difference between a material body and a force was that while a material body possessed mass (inertial mass on the one hand, and gravitational mass or weight on the other) a force did not, and was therefore described as an 'imponderable' constituent of nature.

This picture of the physical world was derived historically from Greek philosophy. From the atomic doctrine of Democritus and Epicurus, physics took the idea that matter consists only of discrete particles; and from Aristotle, the view that matter itself is purely inert. From Aristotle also came the concept of immaterial forces acting upon inert matter and so producing physical changes.

Following Plato's teaching, Aristotle assumed 'an absolutely featureless and purely passive primary matter, void of form till form is impressed upon it'. *Aristotle's 'form' was an active and formative principle which played upon passive matter in the production of physical phenomena.

Plato had declared mind to be the primary cause of the motion of matter – a 'divine demiurge' forming the world through in-

* T. Gomperz, *Greek Thinkers* (1912), vol. 4, p. 85.

dependently existing 'ideas'. Aristotle modified and elaborated Plato's philosophy,* emphasizing the view that matter is purely passive.

Aristotle's 'forms' were non-material agencies of physical change, All motion had its ultimate source in his divine 'prime mover' – the eternal motionless and dimensionless cause of change.†

Scientists who helped to overthrow Aristotelian philosophy in the seventeenth century nevertheless retained its emphasis on the passive inert character of matter. Robert Boyle and Isaac Newton, like Galileo and others, discarded the medieval interpretation of nature derived from Plato and Aristotle. Yet the views of these Greek thinkers remained a powerful influence in scientific circles with regard to the inertness of matter.

While the new natural philosophy of the seventeenth century embraced Greek atomic doctrine, Aristotle's teaching that matter is purely passive found an echo in Newton's insistence that matter is essentially inert. Presenting inertia as the distinguishing characteristic of matter, Newton made room for a supernatural explanation of matter's ceaseless activity.

So too did Robert Boyle, who wrote: 'the origin of motion in matter is from God . . . who by establishing the laws of motion, and by guiding the first motions of the small parts of matter, bring them to convene after the manner requisite to compose the world'.‡ For all his justifiable attack on 'the wranglings and speculations of the schools', Boyle the scientist clung to the idea of a divine 'prime mover', as did Newton.

'When I wrote my treatise,' said Newton about his own monumental work, 'I had an eye upon such principles as might work with considering men, for the belief of a Deity, and nothing can rejoice me more than to find it useful for that purpose.'§ The motions of the planets, he continued, 'could not spring from any natural cause alone, but were impressed by an intelligent agent'‖ . . . 'a divine arm'.¶

Surrounded in Cambridge by Platonists, notably Henry More,

* See James Frazer, *The Growth of Plato's Ideal Theory*, also C. Ritter, *The Essence of Plato's Philosophy*.

† Aristotle, *Physics*, Book 8.

‡ Robert Boyle, *The Origin of Forms and Qualities*, (1667), p. 4.

§ Newton, *Letter to Richard Bentley*, Dec. 10, 1692.

‖ Newton, *Letter to Richard Bentley*, Dec. 10, 1692.

¶ Newton, *Letter to Richard Bentley*, Feb. 11, 1693.

and deeply influenced by Jacob Boehme and other mystics, Newton harked back to Plato for a supernatural interpretation of nature. Newton's own tutor, Isaac Barrow, was an avowed follower of Plato, to whom Newton paid tribute with his concept of absolute space.

Newton's motionless, eternal and dimensionless space was the equivalent of Aristotle's 'prime mover', and of Plato's 'divine demiurge'. Newton's space was the 'boundless sensorium' of God, through which the latter was 'able to form and reform the parts of the universe'.

In the General Scholium to Book III of his *Principia*, Newton made perfectly clear the reason for his emphasis on the exclusive inertia of matter. By picturing matter as absolutely inert, he allowed full scope to God for initiating and guiding the motion of matter.

Two studies in particular bring out this theological aspect of Newtonian theory: J. T. Baker's *Examination of English Space and Time Theories*, and A. J. Snow's *Matter and Gravity in Newton's Physical Philosophy*. Snow sums up Newton's picture of inert matter, 'moved freely by immaterial principles by the agency of its Creator and through the medium of space, the sensorium of God, according to a purpose willed by God'.*

How closely akin these immaterial 'principles' or spiritual 'forces' were to the spiritual 'forms' of Aristotle may be seen from Newton's own words. The General Scholium to the *Principia* includes the following significant passage:

'I might add something on that most subtle spirit which pervades solid bodies and lies hidden in them, by the force and action of which the particles of bodies attract each other at the smallest distances . . . and by which light is emitted . . . and by which all sensation is excited, and the limbs of animals are moved at pleasure . . . But this could not be explained in a few words.'†

Newton refrained from Aristotle's lavish use of words to 'explain' in this way the motion of matter. Nevertheless, the 'spirit' or 'force' which Newton made responsible for physical phenomena was very closely analogous to Aristotle's 'form'.‡

* Newton, *Opticks* (1721), p. 379.
† A. J. Snow, *Matter and Gravity in Newton's Physical Philosophy* (1926), p. 168.
‡ Newton, General Scholium to the *Principia*.

The correspondence between the 'forces' of early physics and the 'forms' of Aristotle's philosophy was noted by Leibnitz, who in a letter to Father Bouvet remarked that 'the forms or entelechies of the ancient thinkers are nothing but forces'. Leibnitz, said Thomas Huxley, was the first scientist philosopher to note that 'the modern conception of Force, as a sort of atmosphere enveloping the particles of bodies, and having potential or actual activity, is simply a new name for the Aristotelian Form'.*

Nineteenth century physicists forgot about Aristotle, and applied the term *force* to any physical cause which they could not explain. Starting with muscular force, a host of other unexplained causes of physical phenomena were postulated. Since matter was allegedly inert, the changes of matter were apparently the result of non-material agencies. *Force* was the term applied to each of these active but elusive intermediaries of physical change, 'inserted between matter and motion from analogy with our muscular sense'.†

Using freely the term *force*, nineteenth century physicists were oblivious of the shadow of Plato upon their manuscripts. They failed to realize that Plato's idea of inert matter, developed by Aristotle into an influential doctrine, was historically responsible for the concept of non-material forces acting upon matter.

Nineteenth century physics assumed that matter was absolutely discontinuous, consisting only of discrete particles separated by empty space. Since matter was also assumed to be absolutely inert, non-material 'forces' were postulated to account for the activity of material particles. All kinds of imponderable forces were postulated as the non-material causes of physical change. Physical phenomena, it was thought, could be reduced to changes in the distribution of inert material bodies, brought about by a variety of non-material forces.

This was the outlook that Newton helped to establish with his one-sided emphasis on the inertia of matter – on the tendency of a body to resist any change of its state of rest or motion.

A body's inertia was found to be measurable. Newton himself devised a method of measuring inertia, and to any quantity of inertia he gave the term *mass*.

* T. H. Huxley, *Essays upon some Controverted Questions* (1892), p. 260.

† H. L. Brose, in E. Freundlich's *Foundations of Einstein's Theory of Gravitation* (1924), p. 123.

Since inertia was allegedly the essential quality of matter, mass was the measure of matter. Newton wrote: 'The quantity of matter is the measure of the same, arising from its density and bulk conjointly. . . . It is this quantity that I mean hereafter everywhere under the name body or mass. And the same is known by the weight of each body for it is proportional to the weight.'*

What was meant by the density of a body? 'By bodies of the same density,' explained Newton, 'I mean those whose inertias are in proportion of their bulks.'† While inertial mass was referred to as density per unit volume, density itself was defined in terms of inertia! In the last analysis, the amount of matter in a body was thus represented by its inertia relative to that of other bodies, by its comparative ability to resist physical change, by its relative capacity for remaining in a particular mechanical state.‡

The mass of a body was considered to be constant, irrespective of its mechanical state. Whatever the changes of motion of a physical system, the total amount of matter present – the total mass – apparently remained the same, this observation giving rise to the principle of the conservation of mass.

Mass and motion were absolutely distinct from one another in being 'mutually inconvertible' (Stallo).

Matter consists only of absolutely discontinuous parts which are measurably inert, their inertial masses always remaining the same. That was the last word of Newtonian mechanics on the fundamental nature of matter.

According to Newtonian mechanics, the space in which matter moved was absolute space – imperceptible, homogeneous and immovable space. This hypothetical absolute space was allegedly non-material and absolutely independent of matter; it was generally regarded as a vacant receptacle or *vacuum*. But while in current opinion this absolute space was mere non-material emptiness, for Newton it was the medium whereby God regulated the motion of matter.

Time in Newtonian mechanics was also an absolute time – an absolutely independent and unchanging 'duration', flowing

* Newton, *The Mathematical Principles of Natural Philosophy*, Book I, Definition I.

† Newton, *Principles*, Book III, Proposition VI, Corollary 4.

‡ See Newton, *Principles*, Book I, Definition IV.

'equably without relation to anything external'.* All physical phenomena were believed to occur *in* absolute space and *in* absolute time.

Absolute space and absolute time were regarded as separate entities, as absolutely independent of one another as they were of material bodies. Relative space and time were allegedly indirect measures of absolute space and time, obtained through observation of bodies in motion, 'Relative apparent and common time is some sensible and external . . . measure of duration by the means of motion . . . Relative space is some movable dimension or measure of the absolute spaces; which our senses determine by its position to bodies'† (Newton).

The following account by the physicist J. B. Stallo, written about 1880, sums up the prevailing view of matter current in the first half of the nineteenth century:

'Forty years ago the creed of an ordinary physicist was something like this: Primordially there existed, through an act of creation or from all eternity, myriads of hard and unchangeable material particles. There also existed certain forces equally unchangeable, such as the forces of attraction and cohesion, heat, electric, magnetic, chemical forces and so on. To the constant or variable, partial or concurrent action of these forces upon the material particles are due all the phenomena of physical reality. In this action the material particles are the passive and the forces the active element; but these elements, of course, preexist to the action. Matter in itself is passive, dead; all motion or life is caused by force; and the only possible solution of the problems of physiology, no less than those of physics and chemistry, consists in the enumeration of the forces acting upon the material particles and in the exact quantitative determination of the effects produced by their action.'‡

In the second half of the nineteenth century, this picture of the physical world was profoundly modified by the concept of energy – a concept which developed as a synthesis of mechanics and primitive thermodynamics. With the discovery of the mechanical equivalent of heat, the principle of the conservation of energy was established by Mayer, Joule and Helmholz.

* Newton, *Principles*, Book I, Scholium to Definition VIII.

† Newton, *Principles*, (1934 ed., p. 6).

‡ J. B. Stallo, *The Concepts and Theories of Modern Physics* (1882), p. 152.

2. Energy

From Newton's day to the middle of the nineteenth century, the 'force' of a moving body had been termed its *vis viva*. This 'living force', as Leibnitz termed it, was measurable in terms of the body's mass and velocity.

Experiments in the second half of the nineteenth century showed that this 'living force' could be transformed, and appear as the same quantity of force in the motion of heat, and in electromagnetic phenomena. With this discovery, *vis viva* ('living force') was seen as a permanent and constant quantity. conserved throughout the whole range of physical change.*

Instead of being merely one among a variety of forces, appearing and disappearing in the flux of physical phenomena, this force was now seen as a 'something' which remained constant in amount. To this force which remained constant throughout any series of physical phenomena, Thomas Young gave the name *energy* – derived from the Greek ενεργός, meaning active.

Previously, the various 'forces' of nature had been regarded as separate and unrelated causes of physical change.

Thomas Young, who coined the term energy, referred to force as 'the cause of a change of motion'.†

J. R. Mayer, who gave the first quantitative formulation of the principle of the conservation of energy, emphasized that 'forces are causes'.‡

Michael Faraday wrote: 'what I mean by the word "force" is the *cause* of a physical action'.§

Helmholz, who gave the first mathematical statement of the principle of the conservation of energy, referred to force as 'that which originates motion'.||

William Thomson (Lord Kelvin) and P. G. Tait, in their well-known *Treatise on Natural Philosophy*, defined a force as 'any

* See W. Magie, *A Source Book in Physics* (1935) ; E. L. Youmans, *The Correlation and Conservation of Forces* (1865).

† Thomas Young, *A Course of Lectures on Natural Philosophy* (1807), vol. I, p. 27.

‡ J. R. Mayer, On the Forces of Inorganic Nature, Liebig's *Annalen* (1842), vol. 42, p. 233.

§ Faraday, Some Thoughts on the Conservation of Force, in *The Correlation and Conservation of Forces* (1865), p. 379.

|| Helmholz, Ueber die Erhaltung der Kraft (1847).

cause which tends to alter a body's natural state of rest, or of uniform motion in a straight line'.*

W. Watson's *Textbook of Physics*, published in 1923, defines a force as 'that which tends to produce a change of motion in a body on which it acts' (p. 65), thus retaining the idea that a force is a cause of physical change.

Forces *had* to be postulated as the non-material causes of physical change. For matter had been stigmatized as absolutely inert, and therefore altogether resistant to physical change.

In 1893, the physicist Oliver Lodge remarked: 'By matter is meant something tangible or resisting.'† And as something essentially 'resisting', matter could not be regarded as a cause or active agency of physical change.

In the same year, another physicist – Professor Mincin – declared that 'the first fundamental axiom of dynamics postulates the existence of force as an entity distinct from matter, space and time. . . '‡

The work of Mayer, Joule, Helmholz, Colding and others, which established the principle of the conservation of energy, simplified the picture of a host of different forces acting as separate and distinct causes of physical change. Investigations showed that only one force – the *vis viva* of Leibnitz – was a constant and transformable cause of physical change.

This particular force (*vis viva*) could now be regarded as the common cause of different physical changes. Instead of a wide variety of quantitatively unrelated forces, this one single force – termed *energy* by Thomas Young – now appeared as the sole active agency of changes in the motion of matter.

Energy was now regarded as *the* cause of changes in the motion of matter. 'The term energy', wrote the physicist J. B. Stallo in 1882, 'denotes the cause of motion.'§

Retaining the old idea of matter as something absolutely inert, physicists now postulated a non-material entity, namely energy, as the sole cause of physical change. Substituting transformable energy for a host of different 'forces', physicists hypos-

* W. Thomson and P. G. Tait, *Treatise on Natural Philosophy* (1879), vol. I, p. 223.

† Oliver Lodge, The Fundamental Axioms of Dynamics, *Nature* (1893), vol. 48, p. 62.

‡ *Report of Proceedings of the Physical Society*, May 26, 1893.

§ J. B. Stallo, *The Concepts and Theories of Modern Physics* (1882), p. 29.

tasized energy into an *entity* – an *active* entity in contrast to allegedly passive matter.

Physics had inherited from Greek philosophy the idea that cause and effect are equal. Upheld by John Bernouilli and other scientists,* this idea was applied by Newton in the formulation of his third law of motion – that 'action and reaction are equal and opposite'.

J. R. Mayer, the Heilbronn physician who became a founder of modern physics, also applied the idea that cause and effect are equal, in formulating the principle of the conservation of energy.

A force is a cause, said Mayer, and is indestructible. When a force is 'expended', therefore, it must be sought in another form, in the effect which it has produced.

Measurement, thought Mayer, should show exactly the equality of cause and effect. By means of measurement, he sought to equate forces and their effect numerically.

Such measurement was simple enough in the case of a mechanical effect of a mechanical cause.

The effect of a force expended in overcoming gravity could be measured in terms of the mass of the body concerned, and the height to which it was raised above the ground. The effect of a force expended in overcoming inertia could be measured in terms of the mass of the body concerned, and the acceleration imparted to it by the force.

For the measurable effect of a force, the French physicist G. G. Coriolis suggested the term *work* – a term first introduced by the engineer J. V. Poncelet in 1829 in his *Mechanique industrielle.*

For his unit of mass, Poncelet adopted the kilogramme; for his unit of height or distance, the metre. Poncelet's unit of work was thus the kilogramme-metre.

In 1807, Thomas Young suggested the term *energy* for the 'living force' of a moving body. With the general adoption of this suggestion, the term *force* (*vis viva*) became synonymous with the term *energy.*

Forces other than the *vis viva* of a moving body were subsequently eliminated from physics, which was thus left with four fundamental quantities – mass, energy, space and time.

* See C. K. Akin, On the History of Force, *Philosophical Magazine* (1864), vol. 28, p. 470.

And of these, energy was regarded as the cause of changes in the motion of matter.

Mass was recognized to be quantity of inertia. Energy, however, was regarded as an entity – an active 'something' distinct from 'passive' matter, and characterized by a 'capacity to do work'.

But work is essentially a transference of energy. To quote Clerk Maxwell, 'work may be considered as the transference of energy from one body to another'.*

Physics thus acquired the following pair of definitions: work is 'transference of energy'. Energy is 'capacity to do work'.

While scarcely illuminating as regards the fundamental nature of energy, this pair of classical definitions marked a tremendous advance in scientific thought. With this advance, the vague idea of equality of cause and effect was replaced by exact calculation of physical change, in terms of mass, energy, space and time.

With this advance, the science of mechanics could give numerical values to causes and their effects. Cause and effect could thus be equated *numerically*, in terms of energy expended and work done.

Kelvin was one of the first scientists to use the new method of calculation. In his papers of 1848 and 1851, he uses the term *work* as synonymous with 'mechanical effect'.

Clausius, in his paper of 1850, was one of the first to use the term *work* with reference to the 'motive power' of heat, following the discovery of the mechanical equivalent of heat by Mayer and Joule.

Mayer and Joule, working independently of one another, discovered that the expenditure of a certain mechanical force resulted in an equivalent amount of heat. Heat, they found, is a form of energy which can be equated numerically with mechanical energy.

Incidentally, Joule's approach to the discovery resembled – contrary to most accounts – Mayer's insistence on the indestructibility of forces which are physical causes. For Joule, to quote his own words, embarked upon his experiments '*satisfied that the grand agents of nature are, by the Creator's fiat, indestructible* and that whenever mechanical force is expended an exact equivalent of heat is always obtained'.†

* Clerk Maxwell, *Matter and Motion* (1920 edition), p. 89.

† Quoted by T. Percy Nunn, Atomism and the Doctrine of Energy, *Proceedings of the Aristotelian Society* (1911-12), New Series, vol. 12, pp. 25-64.

The discovery of the mechanical equivalent of heat was soon correlated with experiments showing the mechanical equivalent of other forms of energy. Previously, several investigators had demonstrated that chemical, electrical and magnetic 'forces' were convertible one into the other. In a paper published in 1840, Faraday had written:

'We have many processes by which the form of the power may be so changed that an apparent conversion of one into the other takes place. So we can change chemical force into electric current, or the current into chemical force. The beautiful experiments of Seebeck and Peltier show the convertibility of heat and electricity; and others by Oersted and myself show the convertibility of electricity and magnetism.'*

The discovery of the mechanical equivalent of heat established the principle of the conservation of energy. In place of a variety of 'forces', energy was now postulated as a single entity – a transformable 'something' which – like matter – remained conserved.

'There are but two classes of things,' wrote the physicist P. G. Tait in 1885, 'matter and energy. Matter is found to consist of parts which preserve their identity, while energy is manifested to us only in the act of transformation . . . Matter is simply passive (inert is the scientific word), energy is perpetually undergoing transformation. The one is, as it were, the body of the physical universe; the other its life and activity.'†

Matter and energy were thus presented as the contrasting elements of physical phenomena, matter tending to resist change, and energy acting as the unique agent of change. Energy, however, was not an entirely free agent. Its classical mathematical definition in relation to a moving body, namely half the product of the body's mass by the square of its velocity, expressed its 'dependence' on matter.

Energy and matter were recognized to be inextricably associated with one another, but this association was not probed deeply by classical physics. 'Energy,' observed P. G. Tait, 'is never found except in association with matter,'‡ a remark which epitomized the understanding as well as the limitations of nineteenth century physics.

* Faraday, *Researches in Electricity*, §207, 1.
† P. G. Tait, *Properties of Matter* (1907), pp. 1, 7.
‡ P. G. Tait, *Properties of Matter*, p. 6.

These, then, were the main conclusions of nineteenth century physics concerning energy, firstly, that energy in a closed system is a constant quantity of 'something' – something necessarily non-material owing to its apparent lack of mass. And secondly, that energy is the active agent of physical change, in contrast to inert matter.

One scientist – Henri Poincaré – attempted to discover a general definition of energy that would reveal its fundamental nature. In this attempt he failed, and fell back on the fact that energy is conserved. 'It is impossible to find a general definition,' wrote Poincaré; 'nothing is left but this – there is something that remains constant.'*

Poincaré failed to understand the fundamental nature of energy because he accepted blindly the assumption that matter is absolutely inert. With this assumption, something non-material had to be postulated to account for changes in the motion of matter.

At first, a variety of independent 'forces' were held to be responsible for physical changes. Later, a transformable force – *vis viva* – was found to be conserved throughout various physical changes. This particular force was named *energy* by Thomas Young.

As a *transformable* 'force', energy accounted for all changes previously attributed to different independent forces. And as a force which remained constant in amount, energy was subject to exact numerical calculation.

The general opinion that energy is an entity – a transformable 'something' – grew out of the belief that matter is absolutely inert. With this prevailing belief that matter is purely passive, energy came to be regarded as a non-material entity responsible for physical change.

3. Ether

The view that matter consists only of discrete bodies, separated by empty non-material space, created a basic difficulty for physics, in so far as phenomena of gravitation, magnetic attraction and electric induction then implied 'action at a distance'. One body – the earth, or a magnet, or an electric coil – could

* H. Poincairé, *Science and Hypothesis* (1905), p. 127.

act upon another body at a distance, apparently without any intervening physical medium!

This was contrary to all rational ideas of nature, and only two kinds of explanation were possible. One was that some supernatural force of a divine character determined the mutual interactions of bodies at a distance from one another, separated by 'empty' space. This mystical interpretation – adopted by Kepler for the gravitational phenomena of the solar system – led away from any scientific inquiry as to the physical basis of 'action at a distance'.

The other interpretation was to postulate the existence of an ethereal substance between discrete bodies, serving as a physical medium for their interactions.* This latter solution was indicated by Descartes; who presented the material universe as consisting of one all-pervading substance – a material ether, from which discrete material particles were formed as 'splinters'.

According to Descartes, the motion of the ether included innumerable vortices, in which discrete bodies were carried along in definite paths. The planetary orbits he ascribed to vortices of the ether,† bearing the planets around the sun like corks in a whirlpool.

Defining matter as that which is extended,‡ Descartes could ascribe to space a material character, since extension§ could be attributed to 'empty' space as well as to material bodies. Space, having the three demensions of extension, was material,|| and therefore the alleged absolute emptiness of a so-called vacuum was a myth.¶

Having defined matter as that which has extension, Descartes drew the logical conclusion that matter is divisible into an indefinite number of parts (not merely a definite number of indivisible atoms). All matter, he also maintained, is in motion, but only motion of its different parts relative to one another.

* Newton's attitude to this problem was non-commital. While rejecting mere 'action at a distance', he did not definitely adopt the hypothesis of an ether.

† Descartes, *Principles*, Part 2, Principles 25-27.

‡ Descartes, *Principles*, Part 2, Principle 4.

§ i.e. length, breadth and depth. See Descartes, *Philosophical Works* (1911 edition), vol. 1, p. 57.

|| Descartes, *Principles*, Part 2, Principles 11, 16. See also *A Discourse on Method*, Part 2, XI.

¶ Descartes, *Principles*, Part 2, Principle 16.

Motion, according to this early relativist, is 'the transference of one part of matter or one body from the vicinity of those bodies that are in immediate contact with it, and which we may regard as in repose, into the vicinity of others'.*

What is it that chiefly distinguishes the Cartesian view of nature from that of Newton? *It is Descartes' view of matter as a relatively continuous and active ethereal substance, divisible into an indefinite number of parts.*

Descartes rejected the Newtonian concept that space is a non-material vacuum, and maintained that a volume of space is essentially a quantity of matter's extension.† Descartes' view contrasts sharply with the Newtonian concept of space as a non-material container of matter.

In common with Galileo and Newton, Descartes sought to reduce all physical change to mechanical motion, and in that respect remained within the limitations of a mechanistic physics. With these limitations we are not at present concerned, save with regard to the question of ethereal motion. This motion was presumed to be translatory as well as rotatory by Cartesian supporters of the ether hypothesis, and the ether was therefore treated as if it were a corpuscular medium behaving like a gas.

This mechanical treatment of 'ethereal' motion came into conflict with many known facts of physical science, and involved Descartes' ether hypothesis in a series of insoluble contradictions. At the same time, the success of Newtonian mechanics gave Newton's view of matter complete supremacy in European thought, to the detriment of Cartesian theory. Partly as a result of this situation, the ether hypothesis – and with it the wave theory of light – was widely discredited during the eighteenth century.

Yet at the end of the seventeenth century, an accumulation of observations supported Huyghen's view that light is a form of wave motion. By that time, Snell had discovered the law of refraction of light, Grimaldi the phenomenon of diffraction, Bartholinus the double refraction of light, Newton the composite character of white light, and Huyghens the phenomenon of polarization.

* *Principles*, Part 2, Principle 25. 'By one body or a part of matter,' continued Descartes, 'I understand all that is transported together, although it may be composed of many parts which in themselves have other motions.'

† Descartes, *Principles of Philosophy*, Part 2, Principle 23.

All these discoveries favoured a wave theory of light. But owing largely to Newton's influence, a wave theory did not become established until the nineteenth century.

In the nineteenth century, however, a wave theory of light did become firmly established and with it came a revival of the ether hypothesis. Based originally on observations of diffraction, polarization and interference, the modern wave theory of light was founded by Young and Fresnel, and was supported by the experimental work of Malus, Brewster, Fizeau, Foucault, Arago and others. This theory entailed the hypothesis of an all-pervading 'luminiferous' ether, filling space and capable of transmitting light in the form of wave motion. The ether hypothesis also gained fresh support from the epoch-making work of Michael Faraday and James Clerk Maxwell.

Faraday found that electrical action was exerted between a primary electric coil and a secondary coil at some distance from it, analogously to magnetic action between a magnet and a distant piece of iron. He came to the conclusion that such action must occur through the properties of some intervening physical structure, and this structure he referred to as space itself.

Rejecting the idea that 'action at a distance' can occur across *empty* space, Faraday sought a *dynamic structure of space* to account for the phenomena of magnetism and electric induction. Space for Faraday was a physical reality, in which 'lines of force' determined the electric and magnetic interactions of bodies at a distance from one another. In 1844, Faraday put forward the theory of electromagnetism which Clerk Maxwell subsequently adopted as the basis of his electromagnetic theory of light, along with a modified ether hypothesis.

But before Clerk Maxwell adopted the ether hypothesis to suit his mathematical description of electromagnetic phenomena. that hypothesis became a source of great difficulties for theoretetical physics, beginning with the idea that the ether is an elastic solid.

'When Young and Fresnel', writes Whittaker, 'put forward the view that the vibrations of light are performed at right angles to its direction of propagation, they at the same time pointed out that this peculiarity might be explained by making a new hypothesis regarding the nature of the luminiferous

medium, namely, that it possesses the power of resisting attempts to distort its shape.'*

In other words, the ether might behave like an elastic solid. Yet at the same time it had to be granted an unparalleled mobility, for in this all-pervading sea of ethereal substance, discrete bodies apparently moved freely, with no sign of ethereal resistance!

A galaxy of scientific talent was associated with unsuccessful efforts to reconcile the contradictory properties of the ether in mechanical terms; to co-ordinate satisfactorily in one mechanical theory such contradictory properties as elasticity and permeability, lability and resistance, compressibility and imponderability. Cauchy, Poisson, Neumann, Navier, Stokes, Kelvin and Green were among the scientists who vainly attempted to give a logical account of the mechanics of the ether in mathematical language.

Not until MacCullagh assumed that the ether was a new kind of material, resistant to rotation but not to compression or shear, did physics approach a partial solution of the problem.

Maxwell's first mathematical demonstration of the electromagnetic nature of light was in 1864. In that year, he brought to fruition a suggestion made by Faraday in 1846.

Faraday had tried to account for the radiation of light without reference to the ether hypothesis. In his communication to Richard Phillips, he suggested the 'lines of force' of electromagnetic fields as the physical basis of light vibrations. He pictured electric and magnetic fields as material 'lines of force' connecting material bodies and transmitting light vibrations.

'In so far as it is admitted', wrote Faraday to Phillips, 'this notion "will dispense with the ether" as the hypothetical medium of light vibrations. The view which I am so bold as to put forth', he continued, 'considers radiation as a high species of vibration in the lines of force which are known to connect particles and also masses of matter together. It endeavours to dismiss the ether, but not the vibrations.'†

Faraday could put forward this revolutionary idea because

* E. T. Whittaker, *A History of the Theories of Aether and Electricity* (1910), p. 137. See also J. Larmor, *Aether and Matter* (1900).

† Faraday, Communication to Richard Phillips, *Philosophical Magazine*, 3rd Series (1846), vol. 28, p. 345.

he regarded matter as continuous and active, not as discontinuous inert particles of orthodox contemporary theory. He had previously written as follows on matter and space:

'I feel great difficulty in the conception of atoms of matter which in solids, fluids and vapours are supposed to be more or less apart from each other, with intervening space not occupied by atoms, and perceive great contradictions which flow from such a view. . . . *The difference between a supposed little hard particle and the powers around it I cannot imagine.* The matter of one atom touches the matter of its neighbour. *Hence matter will be continuous throughout,* and in considering a mass of it we have not to suppose a distinction between its atoms and an intervening space. In the view of matter now sustained . . . *matter and the atoms of matter would be mutually penetrable* . . . *matter fills all space,* or, at least, all space to which gravitation extends. . .'*

In his communication to Richard Phillips (1846) Faraday again expressed the view that matter is continuous. Reaching the revolutionary conclusion that the material volume of a particle is as extensive as its surrounding electric or magnetic field, he said: 'That which represents size may be considered as extending to any distance to which the lines of force of the particle extend.'

While developing Faraday's idea of electric and magnetic fields into the electromagnetic theory of light, Clerk Maxwell still postulated the ether as the physical medium of light vibrations. While referring to Faraday's fields as fields of space,† Maxwell clung to the idea of a mechanical ether filling space and transmitting the vibrations of light.‡

Ironically enough, the Michelson-Morley experiment, which led to the abandonment of the mechanical ether hypothesis, was probably prompted by Maxwell's letter of 1880, in which he suggested to Albert Michelson that the motion of the earth through the ether would affect the velocity of light!

In his famous paper, A Dynamical Theory of the Electromagnetic Field, Maxwell wrote: 'The Electromagnetic Field is

* Michael Faraday, A Speculation Touching Electric Conduction and the Nature of Matter, *Philos. Mag.*, 3rd Series (1844), vol. 24, p. 136.

† Maxwell, *Scientific Papers* (1890), vol. 1, p. 527.

‡ Maxwell, *Scientific Papers* (1890), vol. 2, p. 322.

that part of space which contains and surrounds bodies in electric or magnetic conditions. It may be filled with any kind of matter, or we may endeavour to render it empty of all *gross* matter, as in the case of Geissler's tubes and other so-called vacua. *There is always, however, enough of matter left to receive and transmit* the *undulations of light and heat* . . . we are obliged to admit that *the undulations are those of an ethereal substance,* and not of the gross matter, the presence of which merely modifies in some way, the motion of the ether. . . . '* (our italics).

In this paper, the mathematical equations of which are the foundations of modern electrodynamics, Maxwell insisted that in so-called empty space there is always 'ethereal' matter capable of transmitting electromagnetic radiation. The theory, Maxwell states, 'may be called a theory of the electromagnetic field, because it has to do with the space in the neighbourhood of electric or magnetic bodies, and it may be called a dynamic theory, because it assumes that in that space there is matter in motion'.

Maxwell's equations gave a satisfactory mathematical account of the 'ethereal' transmission of light, but did not solve outstanding problems of the ether hypothesis. Maxwell's ether was suitable enough for a mathematical description of the passage of light through 'empty space', but there remained the question of the mechanical relations between material bodies and the ether. The *mechanics* of the ether remained an apparently insoluble puzzle.

The trouble lay in the false assumption that the physical 'medium' of light must necessarily be either at rest or in mechanical motion. This false assumption proceeded from an acceptance of Newton's concept of absolute space independent of matter.

Having assumed that for all practical purposes this independent space was non-material emptiness, physicists were obliged in theory to *fill* space with the ether, in order to account for the wave-motion of light *in vacuo.* And having theoretically *filled* space with an ethereal medium, physicists were led logical y to the supposition that this ether might undergo translatory motion *in* space, in the manner of discrete material bodies.

* Clerk Maxwell, *Philosophical Transactions of the Royal Society of London* (1865), vol. 155, p. 459.

Hence it appeared possible to detect local motion of the ether; or, if the whole ether was stationary, to detect the motion of material bodies relative to the ether. An experimental attack was therefore made on the problem of the ether in relation to the mechanical motion of discrete material bodies – from planets* to particles.

Herz, who had confirmed Maxwell's theory in discovering electromagnetic radiation with a hitherto unknown range of wave-length, followed Stokes in asserting that the ether in or around a moving material body is *completely* carried along with that body. But this conclusion was contrary to the result of Fizeau's experiment, to experiments with moving insulators performed by Roentgen, Eichenwald and Wilson,† and to the facts of stellar aberration.

The view that the ether in the neighbourhood of a moving body is *partially* carried along with that body had been put forward by Fresnal, but this view too proved untenable, leaving only one other alternative, namely that the ether is entirely stationary, and is not carried along at all by moving bodies. This last alternative was the conclusion adopted at the end of the nineteenth century by Lorentz, who presented the ether as a medium absolutely immobile as far as mechanical motion is concerned.

Lorentz thus sharpened the distinction between the ether and corporeal matter, only the latter being considered capable of mechanical motion. The ether, on the other hand, was given by Lorentz a complete monopoly of electromagnetic properties, except for the carrying of electric charges by material particles.

'Lorentz', wrote Einstein, 'considered the ether to be intrinsically independent of matter, both from a mechanical and a physical point of view. The ether did not take part in the motions of matter, and a reciprocity between ether and matter could be assumed only in so far as the latter was considered to be the carrier of attached charges. The great value of the theory of Lorentz lay in the fact that the entire electrodynamics of bodies at rest and of bodies in motion was led back to Maxwell's equations. . . . The theory appeared to be unsatisfactory only

* In astronomy, the question of the motion of celestial bodies relative to the ether was raised by the phenomenon of stellar aberration, discovered by Bradley in 1725.

†See A. V. Vasiliev, *Space, Time, Motion* (1924), p. 136.

in one point of fundamental importance. It appeared to give preference to one system of co-ordinates of a particular state of motion (at rest relative to the ether) as against all other systems of co-ordinates in motion with respect to this one.'*

In other words, Lorentz adhered to Newton's conception of an independent and absolutely immovable space, in which he postulated an equally independent and immovable ether. Any body at rest relative to the other would thus be at rest relative to absolute space. Such a body would then be in a state of absolute rest, and would therefore constitute a 'privileged' unique co-ordinate system. This would be unsatisfactory for physics, since it would contradict the principle of the relativity of uniform motion established by actual physical observations.

Newtonian time as well as Newtonian space was also adhered to in the last resort by Lorentz. For although he and Larmor had introduced a 'local' time for each moving body, 'it was not suggested that the observer in the moving system would be deceived into thinking that it was the real time.'†

Adhering to Newtonian ideas of space and time, Lorentz indicated that the motion of material bodies relative to a stationary ether could and would be detected. And in the expectation of detecting this motion, Michelson and Morley devised the famous experiment whose repercussions are still shaking the scientific world.

Carried out in 1887, the Michelson-Morley experiment was designed to show the motion of the earth relative to an allegedly immobile ether‡ filling all space. It was, therefore, in this respect, an attempt to detect the motion of the earth relative to absolute space itself; in other words, an attempt to detect absolute motion.

The apparatus of the experiment was a delicate interferometer, capable of detecting the orbital motion of the earth relative to the ether (if, as was thought, such motion actually existed). The apparatus directed one ray of light parallel to the direction of the earth's orbital motion; and another at right-angles to it. The orbital motion of the earth relative to the

* Einstein, A Brief Outline of the Development of the Theory of Relativity, *Nature*, Feb. 17, 1921.

† Eddington, *Space, Time and Gravitation* (1921), p. 211.

‡ i.e. *mechanically* immobile, but capable of transmitting electromagnetic radiation.

ether – if such motion had existed – would have produced interference between these two rays of light.

But the Michelson-Morley apparatus failed to detect any such motion! The earth moves in its orbit with a velocity of some 18½ miles per second; but relatively to the supposedly stationary ether around it; no motion of the earth could be demonstrated! This was the 'negative' result of one of the most far-reaching experiments ever performed!

To account for the unexpected result of the Michelson-Morley experiment, Lorentz introduced in 1895 the assumption that every body contracts on motion in the direction of its motion, by an amount proportional to its velocity. This explanation – made independently by FitzGerald in 1892 – accounted for the negative result of the experiment, on the assumption that the apparatus itself contracts in the direction of the earth's orbital motion, thus preventing the interference between the two light-rays which would otherwise have appeared.

But this explanation – which adhered implicitly to the idea that the earth really did move relatively to the ether and thus to absolute space – suffered from one peculiar drawback, namely the absolute impossibility of ever demonstrating any such contraction through the direct measurement of one body by another. For both the measuring and the measured bodies would contract proportionately in the direction of their motion, and any direct comparison of one with the other would therefore fail to show the contraction!

Lorentz nevertheless maintained at first that every body actually undergoes a physical contraction in the direction of its motion. 'There can be no question,' he said, 'about the reality of this change of length.'* Other experiments, however, carried out by Rayleigh, Brace, Trouton, Noble and Rankine in attempts to demonstrate the physical reality of the FitzGerald-Lorentz contraction, all gave negative results.† The contraction had been postulated as a physical reality, but it could not be demonstrated as such!

* Quoted by W. N. Bond, *Science Progress* (1937-38), vol. 32, p. 79.

† The most recent and accurate experiment designed to detect any physical Lorentz contraction was that of G. A. Tomlinson and L. Essen on piezo-electric crystal vibration (*Proceedings of the Royal Society*, 1937, Series A, vol. 158, p. 606). This, too, gave a negative result.

An explanation of the Michelson-Morley experiment had been given, but the explanation defied experimental verification! Motion of the earth relative to the ether was still assumed to exist, but apparently it could never be detected owing to the very nature of things! Physics had reached an impassé. Newton's religious concept of absolute space, subject to divine supervision but not to direct human observation, had led physical science into a cul-de-sac. From this critical point of development, physics was led into new fields of exploration by the revolutionary genius of Einstein.

Chapter II

PRINCIPLES OF THE THEORY OF RELATIVITY

1. The Special Theory of Relativity

The boldness of Einstein's interpretation of the Michelson-Morley experiment lay in its novel simplicity. Einstein took the bare result of the experiment at its face value, and concluded that light travels at the same velocity, regardless of the motion of its source. Hence the failure of the two rays of light (one in the direction of the earth's orbital motion, the other at right-angles to it) to show interference. Einstein concluded that light from a terrestrial source is not affected in its velocity by the motion of the earth, and with this conclusion he established his fundamental postulate that the velocity of light *in vacuo* is constant.

In 1913, the principle of the constancy of the velocity of light *in vacuo* was confirmed by de Sitter through his observations on light from binary stars. (Only two years later the limitations of the principle were revealed by the general theory of relativity!)

The conclusion that light *in vacuo* always travels at the same velocity permitted a new interpretation of the FitzGerald-Lorentz contraction, the existence of which *as a phenomenon of measurement* was established by the theory of relativity. This theory showed that the constancy of the velocity of light affects measurements of a distant moving body made by means of light-signals, in such a way as to give the *appearance* of a physical contraction in the direction of motion.

The Fitzgerald-Lorentz contraction is an appearance due to the method of measurement, the degree of apparent contraction depending on the velocity of the observed body relative to the system of reference of the observer. In itself, however, the body undergoes no physical contraction. 'The contraction is only a consequence of our way of regarding things and is not a change of a physical reality'* (Born).

* M. Born, *Einstein's Theory of Relativity* (1924), p. 213.

Lorentz had postulated an actual physical contraction of a moving body in the direction of its motion – a contraction independent of human measurements. This postulate left intact the idea that a motionless ether fills a motionless space.

According to Lorentz, the contraction of bodies on motion conceals the existence of such an ether, which is nevertheless present as the physical medium of electromagnetic radiation. To this theory Einstein pointed out a serious objection, namely its opposition to the relativity principle of classical mechanics.

With the ether out of the picture, classical mechanics was unassailable in its contention that of two bodies, A and B, in uniform motion relative to one another, either body could equally well be chosen as a co-ordinate system for describing the laws of motion. The body A could be regarded as in motion relative to B; or – with equal justification – B could be regarded as in motion relative to A.

The hypothesis of a motionless ether, however, implied that at the same time the body A could be at rest relative to the motionless ether, *i.e. absolutely at rest.* The body A would then constitute a unique co-ordinate system, not at all equivalent to B as a frame of reference for describing the laws of motion.

On this point, wrote Einstein, the theory of Lorentz 'seemed to stand in direct opposition to classical mechanics, in which all inertial systems which are in uniform motion with respect to each other are equally justifiable as systems of co-ordinates'.*

Einstein's alternatives to the Lorentz theory of a stationary ether was to postulate the constancy of the velocity of light *in vacuo.* This postulate explained the result of the Michelson-Morley experiment without recourse to a supposedly physical contraction of the apparatus in the direction of the earth's motion.

From the result of the Michelson-Morley experiment, Einstein concluded that light travels at a constant velocity, regardless of the motion of its source. This conclusion permitted Einstein to demolish the motionless ether hypothesis, which conflicted with the relativity principle of classical mechanics.

Physics was thus left with a hypothetical ether that was evidently not in mechanical motion, and could not be regarded as at rest! This involved the complete abandonment of the ether

* Einstein, *Nature*, Feb. 17, 1921.

hypothesis. Since the ether could not be regarded as either at rest or in mechanical motion, the whole ether hypothesis had to be abandoned. There could be no place in mechanics for the idea of a physical medium in no mechanical state at all!

The theory of relativity thus removed the ether from mechanics, and with it all idea of any physical system in a state of absolute rest. Straightforward though it was, this theoretical step had the most profound repercussions in physics, since it demolished Newton's conception of an absolute motionless space.

Having shown the idea of a motionless ether filling a motion-space to be untenable, Einstein removed all reason for referring to such a space. Indeed, the Newtonian hypothesis of an empty motionless space now became inconsistent with Newtonian mechanics, since it demanded the all-pervading presence of a moving or motionless ethereal medium to account for electromagnetic radiation. And experiment as well as theory had ruled out the existence of such a medium. Hence it was necessary to banish Newtonian absolute space from the realm of physics, while retaining the relativity principle of Newtonian mechanics concerning uniform rectilinear motion.

In order to preserve the kernel of relativity in Newtonian theory, Einstein was obliged to strip away from that theory its metaphysical husk. Einstein discarded Newton's metaphysical notion of a motionless and imperceptible absolute space, in favour of the relativity principle concerning uniform rectilinear motion. That principle has been expressed as follows: 'All systems of reference which are in uniform rectilinear motion with regard to one another can be used for the description of physical events with equal justification.'*

The special theory of relativity did not stop short at overthrowing Newton's concept of absolute space. With irresistible logic, its founder proceeded to demolish Newton's concept of absolute time. Pointing out that the only time relevant to physics is clock time, Einstein examined afresh how time measurements are made.

Lorentz and Larmor had shown that measurements of time, like measurements of space, depend upon the co-ordinate

* E. Freundlich, *The Foundations of Einstein's Theory of Gravitation* (1924), p. 118.

system adopted. Time measurements vary according to the relative motion of the clocks concerned. Each reference body (co-ordinate system) thus has its own 'local' time.

Lorentz, however, thought that each reference body moved in Newton's universal time, which was allegedly independent of bodies in motion. This view created an intolerable situation in the science of kinematics, since it showed a universe broken up geometrically into the innumerable 'local' spaces of moving reference bodies, each body having two times – Newtonian universal time and its own apparent local time!

Einstein rescued kinematics from this situation by insisting that the local 'apparent' time of a system's clock is the *only* clock time of that system. Einstein based his view on the principle that time – numerically speaking – is the time of particular clocks.

In other words, a numerical definition of time is relative to the measuring instrument used to obtain that definition. Clock time, consisting of numerical definitions given by clock measurements, is relative to the state of rest or motion of the clock concerned.

To quote Einstein's own words on the subject: 'Every reference-body (co-ordinate system) has its own particular time. Unless we are told the reference-body to which the statement of time refers, there is no meaning in a statement of the time of an event.'*

Einstein's bold step in abandoning the Newtonian idea of one independent universal time was not sufficient to create a new kinematical theory, since there was not yet a means of integrating local spaces and local times into a single world picture of mechanical motion.

A new theoretical basis for spatial and temporal measurements was necessary before a general form could be given to the principle of relativity. This basis was provided by Minkowski.

In 1908, Minkowski showed how time could be considered as a fourth dimension, inseparably associated with the three dimensions of space. 'Nobody has ever noticed a place except at a time,' said Minkowski, 'or a time except at a place.'

In Minkowski's mathematical 'world', the universe is

* Einstein, *The Theory of Relativity* (1921), p. 26.

abstractly stripped to the limit of physical qualities. All that remains is a spatio-temporal skeleton, the bones of which are four dimensions – three of space and one of time.

Representing the four dimensions of space-time by the co-ordinates *x*, *y*, *z*, *t*, and each material body by a 'substantial point', Minkowski created a mathematical map of mechanical motion, on a cosmic scale. He said:

'A point of space at a point of time, that is, a system of values, *x*, *y*, *z*, *t*, I will call a *world-point*. The multiplicity of all thinkable *x*, *y*, *z*, *t* systems of values we will christen *the world*. . . . We fix our attention on the substantial point which is at the world-point *x*, *y*, *z*, *t* and imagine that we are able to recognize this substantial point at any other time. Let the variations *dx*, *dy*, *dz* of space co-ordinates correspond to a time element *dt*. Then we obtain an image, so to speak, of the everlasting career of the substantial point, a curve in the world-line. . . . The whole world is seen to resolve itself into similar world-lines . . . in my opinion physical laws might find their most perfect expression as reciprocal relations between world-lines.'*

Henceforth, declared Minkowski in heralding the great discovery, 'space by itself, and time by itself, are doomed to fade into mere shadows, and only a kind of union of the two will preserve an independent reality'. Amplifying Minkowski's famous declaration, we can now say something more about the 'independent reality' which is a union of space and time.

The two most fundamental modes of existence of matter, namely extension and motion, form a dialectic unity, and this unity is subject to measurement with measuring rods and clocks.

Measuring extension with standard rods, we define quantities of extension numerically, in terms of space.

Measuring motion with standard clocks, we define quantities of motion numerically, in terms of time.

Measuring extension and motion conjointly, with measuring rods and clocks, we define spatio-temporal quantities numerically.

In using Minkowski's method of describing space-time, Einstein adopted the mathematical method of Gauss for identifying spatio-temporal 'points'.

Gauss treated a surface as a collection of mathematical points

* H. Minkowski, Space and Time (1908), in *The Principle of Relativity* (1923), pp. 75, 76.

infinitely close to one another in two spatial dimensions, constituting a two-dimensional *continuum.* Each point is labelled with two numbers (co-ordinates) representing its position relative to other points of the surface, and thus preserving the identity of the point whatever the shape assumed by the surface as a whole. The two sets of numbers indicating all the points of a curvilinear surface are Gauss' 'curvilinear' co-ordinates.

These Gaussian co-ordinates are 'nothing more than an association of two sets of numbers with the points of the surface considered, of such a nature that numerical values differing very slightly from each other are associated with neighbouring points in "space" '* (Einstein).

Gauss' method, wrote Einstein, 'can be applied also to a continuum of three, four or more dimensions. If, for instance, a continuum of four dimensions be supposed available, we may represent it in the following way. With every point of the continuum we associate arbitrarily four numbers, x_1, x_2, x_3, x_4, which are known as "co-ordinates". Adjacent points correspond to adjacent values of the co-ordinates. . . . To every point of a continuum are assigned as many numbers (Gaussian co-ordinates) as the continuum has dimensions . . . numbers which differ by an infinitely small amount are assigned to adjacent points'.†

As mathematical instruments for creating the general theory of relativity, Einstein thus had Minkowski's treatment of space-time and Gauss' curvilinear co-ordinates. To these he added the mathematical method of tensor analysis‡ developed by Riemann, Ricci, Levi-Civita and others.

With these mathematical instruments, Einstein fashioned Faraday's concept of physical fields into a new theory of gravity, and was thereby able to forge the general theory of relativity. In this operation, taking into account the motion of accelerated bodies, it became evident that Euclid's geometry does not represent the actual structure of cosmic space.

'Considerations based on the material results of the special

* Einstein, *The Theory of Relativity*, p. 89.

† Einstein, *The Theory of Relativity*, pp. 89, 90.

‡ Tensor analysis is a method of formulating differential equations which remain unchanged in form (convariant) for all transformations of their variables. A *tensor* is a magnitude expressed by many numbers (as in the case of the pressure inside an elastic body, or the stresses in a solid), in contrast to a *scalar*, which is a magnitude expressed by one number.

theory of relativity led to the result that Euclidean metrics can no longer be valid with respect to accelerated systems of co-ordinates.'* Einstein therefore turned to Riemann's non-Euclidean geometry in order to bring acceleration within the scope of the relativity principle.

Applied to the gravitational field, Riemann's geometry permitted a mathematical description of the field's essential spatio-temporal relations, expressed as a certain 'metric'.

The postulates of any geometry constitute a system of measure-relations, the general mathematical expression of which is a certain 'metric'. In pure geometry, set apart from physical phenomena, a metric represents an abstract mathematical theory, the only requirement of which is that its statements must be consistent with one another. Here the only criterion of a metric's validity is the internal consistency of the geometry as a purely abstract structure.

When, however, a geometrical theory is applied in practice to physical phenomena, its validity depends furthermore on a correspondence between theory and practice. Experience then determines whether or not the metric actually corresponds to the essential spatial relations of the physical phenomena concerned. Experiments and observations then decide whether the geometrical theory fits the relevant facts. Measurements then determine the validity of the metric as far as physical reality is concerned.

The Euclidean metric represents a set of geometrical principles based historically on the rigidity and configuration of terrestrial solid bodies. Material cubes, spheres and other rigid bodies were the concrete foundations of the mathematical abstractions of Euclidean geometry.†

Prior to the twentieth century, the preoccupation of mechanics with rigid bodies preserved the generally accepted assumption that Euclidean geometry was the only geometry valid for the physical world. Euclid's axioms were termed 'self-evident' truths, and were formally elevated by Kant to the status of *a priori* knowledge, purely mental in origin and needing no experimental proof of their validity.

But while Kant was bestowing this metaphysical crown upon

* Einstein, *Nature*, Feb. 17, 1921.

† See Helmholz, The Origin and Meaning of Geometrical Axioms, *Mind* (1876), vol. 1, p. 301.

Euclidean geometry, K. E. Gauss was engaged in drawing its axioms into the domain of experimental investigation, so denying Euclid's axioms any *a priori* validity.

In his famous mountain peak experiment, Gauss neither proved nor disproved Euclid's proposition that the three interior angles of any triangle are together equal to two right-angles, but he did perceive the possibility of the non-Euclidean geometry that was first worked out by N. I. Lobachevski, and independently by J. Bolyai.

In 1826, Lobachevski read a revolutionary paper before the Physico-Mathematical Faculty of the University of Kazan, saying: 'The ideas of geometry do not contain the truth which they wish to prove and which can only be verified like other physical laws by experiments, for example by astronomical observations.' Shaking himself free from intellectual servitude to Euclidean assumptions. Lobachevski later formulated the principles of a consistent non-Euclidean geometry, in which parallel lines always meet.

In the same year that Lobachevski read his challenging paper, G. F. B. Riemann was born, and in his youth this forerunner of Einstein also worked out a consistent non-Euclidean geometry – one in which parallel lines do not exist at all. It was this Riemannian geometry that Einstein eventually adopted in formulating his general theory of relativity.

2. The General Theory of Relativity

The development of the general theory of relativity proceeded from Einstein's continued efforts to build a physics valid for *all* co-ordinate systems, including those for which Newton's law of inertia does not hold.

The special theory of relativity had considered only co-ordinate systems moving with uniform velocity relative to one another, so that by means of the Lorentz transformation any such system could be chosen as well as another in formulating the laws of mechanics. All inertial systems thus became equivalent for stating the laws of mechanical motion, and those laws were thereby emancipated from any one unique rigid body *as far as uniform velocity was concerned.*

In the real world of physical phenomena, however, *there is no such thing as a rigid body moving with a uniform velocity!* Every moving body is found to be changing its speed or direction (or both), if there is no restriction on a choice of reference bodies. In the last analysis, every moving body is an accelerating body, and is thus a physical system to which Newton's law of inertia does not apply. In other words, inertial systems do not actually exist as far as the universe in general is concerned, and in that respect uniform velocity is an ideal abstraction which does not apply concretely to any moving body.

Hence the special theory of relativity did not cover the conditions of motion actually existing in the physical world, and could not give the laws of motion a universal validity, irrespective of the body of reference chosen for their formulation. Therefore the problem still facing Einstein before 1915 was to state the laws of mechanical motion in such a way that their general validity did not depend on any one unique co-ordinate system.

In particular, the problem was to reach an understanding of acceleration as would enable the laws of mechanical motion to be stated independently of any one particular accelerating body. The solution of this problem did in fact emancipate the laws of motion from all rigid bodies as bodies of reference, by providing co-ordinate systems belonging only to space and time. Let us trace briefly the main development of ideas in Einstein's progress towards this solution.

For a free moving body, i.e. for a moving body not acted upon by electromagnetic agencies or contact with other bodies, classical mechanics postulated two possible causes of acceleration; one was gravity, the other was inertia. Classical mechanics presented gravity and inertia as the *two* basic tendencies or qualities of matter. The quantitative expression of a body's subjection to gravity was its gravitational mass, while the quantitative expression of its subjection to inertia was its inertial mass.

The gravitational mass and the inertial mass of a body were found to be numerically equal by Newton, and in 1890 by Eötvös.

In pre-relativity physics, this numerical equality of a body's gravitational mass and its inertial mass was quietly ignored, if not attributed to a divine miracle or a chance accident! To

Einstein, however, it suggested the possibility that gravity and inertia themselves might be *physically identical.* In working out this idea, Einstein arrived at an understanding of acceleration that allowed him to emancipate the laws of mechanical motion from all rigid bodies as co-ordinate systems. On this fundamental point, Einstein wrote: –

'I was struck by the fact that the force of gravitation possesses a fundamental property, which distinguishes it from electromagnetic forces. All bodies fall in a gravitational field with the same acceleration or – what is only another formulation of the same fact – the gravitational and inertial masses of a body are numerically equal to each other. This numerical equality suggests identity in character. Can gravitation and inertia be identical? This question leads directly to the general theory of relativity.'*

Einstein concluded provisionally that gravity and inertia were actually one and the same physical quality. But what was the action of gravity? Was it 'action at a distance' between two bodies, with no intervening physical medium? Michael Faraday did not think so.

'Faraday,' wrote Clerk Maxwell, 'never considers bodies as existing with nothing between them but distance, and acting on one another according to some function of that distance. He conceives all space as a field of force, the lines of force being in general curved, and those due to any body extending from it on all sides, their directions being modified by the presence of other bodies'.†

It was this concept – hitherto ignored as far as gravity was concerned – which Einstein adopted for his new interpretation of gravitational phenomena. In place of the idea of gravitational 'action at a distance' between material bodies (with no intervening physical medium), Einstein introduced the concept of a gravitational *field,* the physical structure of which is determined by the masses of material bodies. The gravitational motion of bodies in this field is determined by the field structure which the bodies themselves create.

Material bodies mould surrounding gravitational field structure, and the structure of the field is responsible for the

* Einstein, *Nature,* February 17, 1921.

† Quoted by E. T. Bell, *The Handmaiden of the Sciences* (1937), p. 177.

gravitational motion of the bodies in it – such is Einstein's general view of the action of gravity, which he himself puts in the following words: –

'As a result of the more careful study of electromagnetic phenomena, we have come to regard action at a distance as a process impossible without the intervention of some intermediary medium. If, for instance, a magnet attracts a piece of iron, we cannot be content to regard this as meaning that the magnet acts directly on the iron through the intermediate empty space, but we are constrained to imagine – after the manner of Faraday – that the magnet always calls into being something physically real around it, that something being what we call a 'magnetic field'! In its turn this magnetic field operates on the piece of iron, so that the latter strives towards the magnet. . . . The effects of gravitation also are regarded in an analogous manner. The action of the earth on the stone takes place indirectly. The earth produces in its surroundings a gravitational field, which acts on the stone and produces its motion of fall.'*

With this fundamental idea, that the action of gravity is the effect of a physical field moulded by material bodies and determining their mutual attraction, Einstein was able to show that inertia and gravity are two manifestations of one and the same physical quality.

According to this 'principle of equivalence' acceleration due to inertia is equivalent to acceleration due to gravity, the only difference being in the conditions of observation. 'The same quality of a body manifests itself according to circumstances as "inertia" or as "weight". This principle leads directly to the general theory of relativity, which elucidates motion from the structure of the gravitational field.'†

The geometrical structure of the gravitational field is formulated in terms of curvature, which is a mathematical quantity describing any deviation from Euclidean space.

If the curvature of space is a positive quantity, the straightest line is curved. There are no Euclidean straight lines in space with positive curvature. The greater the curvature, the more curved is the straightest line. And the greater the mass of bodies in the vicinity, the greater is the curvature. Proof of this is

* Einstein, *The Theory of Relativity* (1921), pp. 63, 64.

† Einstein, *The Theory of Relativity*, p. 65.

given by the behaviour of light from the stars in the vicinity of the great mass of the sun.

Light travels in straightest lines (goedesics). Close to the sun, light-rays are bent in accordance with relativity theory, a fact first observed during the solar eclipse of 1919.

In his general theory, Einstein showed precisely how the curvature of the gravitational field is determined by the masses and velocities of material bodies. The presence of astronomical bodies 'distorts' the gravitational field, the space or space-time of which is thus given a certain curvature. In turn, the field's space-time structure determines the velocities of free moving bodies, causing them to travel in straightest possible paths (geodesics).

Bodies which are not interfered with move in geodesics.* That is Einstein's law of motion, based upon his theory of the gravitational field.

Before considering some of the profound changes in our view of the physical world brought about by the theory of relativity, we may pause for a moment on the general approach of Einstein to the problems confronting him.

Einstein developed the theory of relativity without doing any physical experiments of his own. It was by interpreting the experiments of others, particularly of Michelson and Morley, that Einstein arrived at relativity mechanics. He began by rescuing the relativity principle of classical mechanics from Lorentz' hypothesis of a stationary ether, but this defence of relativity regarding uniform motion undermined the root assumptions of Newtonian mechanics.

It took courage as well as logic to challenge the validity of Newton's idea of space and time. Einstein was successful in his challenge because he was ready to discard traditional authority in favour of logical conclusions, while making a sustained drive to prove the correctness of a well-conceived idea. It was his continued effort to prove that all mechanical motion is relative which revolutionized the science of mechanics. In proceeding perseveringly and undaunted towards this proof, Einstein opened men's eyes not only to errors of Newtonian thought, but also to an unexplored ocean of problems and possibilities.

* W. de Sitter, *Relativity and Gravitation* (1921), p. 214.

Chapter III

FIELDS AND PARTICLES

1. Fields

Among the revolutionary consequences of the theory of relativity was the demonstration that mass and energy are equivalent quantities.

A quantitative relationship between mass and energy had been perceived by Clerk Maxwell, who in 1873 concluded that a beam of electromagnetic radiation falling on an absorbing surface would produce a mechanical pressure, due to the mass of the radiant energy, Maxwell's conclusion was confirmed experimentally by P. N. Lebedev in 1900, and by E. F. Nicholls and G. F. Hull in 1903.

Investigating the relationship between mass and energy, Einstein formulated the equivalence of these two quantities: 'A body of mass m is to be regarded as a store of energy of magnitude mc^2'* (where c is the velocity of light *in vacuo*).

Equally so, 'the special theory of relativity finally led to the conclusion that all energy must be accorded the property of inertia. . . . Inertial mass is a property of every kind of energy'.†

The discovery that mass and energy are equivalent quantities had a shattering impact on the Newtonian concept of matter.

Newton had insisted that *the* characteristic feature of matter is inertia, which he defined as a 'power of resisting' mechanical change, and as a 'force of inactivity'.‡ Newton applied the term *mass* to the amount of a body's inertia, and he regarded mass as an amount of matter.

Mass represents matter. Matter is that which has mass. Such was the prevailing opinion from Newton's day until the establishment of relativity theory. *At the same time, it was thought*

* Einstein, *Nature*, February 17, 1921.

† E. Freundlich, *The Foundations of Einstein's Theory of Relativity*, p. 91.

‡ Newton, *Principia*, Book I, Definition I.

that matter consists only of absolutely discontinuous particles in empty space.

With the discovery that energy-containing fields possess inertia, an insoluble contradiction appeared in this Newtonian concept of matter, for fields do not consist of particles.

Maxwell, asking where energy resides in electromagnetic phenomena, had written: 'On the old theory it resides in the electrified bodies, conducting circuits, and magnets in the form of an unknown quantity called potential energy, or the power of producing certain effects at a distance. On our theory it resides in the electromagnetic field, in the space surrounding the electrified and magnetic bodies, as well as in those bodies themselves.'*

The development of field physics established the fact that electric and magnetic fields are stores of energy, and possess the quality of inertia. An electric current, for example, is surrounded by a magnetic field with a certain energy content. Any sudden increase or decrease of current is opposed by this field. The energy-containing field retards any increase or decrease of the current, thus exhibiting the quality of inertia in the phenomenon of self-induction.

An electric or a magnetic field is a store of energy and therefore has inertia, measurable in terms of mass. This electromagnetic mass is identical with mechanical mass.† *But while electric and magnetic fields behave like matter in showing the quality of inertia, they do not consist of particles.*

A physical field is a continuous structure which is subject to measurement, but not to counting as in the case of material particles. A physical field is a continuous structure which can be considered abstractly as an infinite number of points, lines or other geometrical elements, but does not consist concretely of discrete physical parts. A field has not the discontinuous structure of corporeal matter.

Matter cannot therefore be defined specifically in terms of inertia *and* a discontinuous particle structure, since continuous electric and magnetic fields also exhibit the quality of inertia. The fact that continuous fields exhibit inertia excludes the

* Maxwell, A Dynamic Theory of the Electromagnetic Field, *Philosophical Transactions of the Royal Society of London* (1865), vol. 155, p. 459.

† See L. Infeld and B. Hoffman. *Physical Review* (1937), vol. 51, p. 765.

Newtonian concept that matter is uniquely distinguished by inertia *and* by a discontinuous particle structure.

Field theory presented physics with the following choice in defining matter: *either* matter consists only of discrete particles, *or* matter is 'that which has mass'.

Presented with this choice, physicists have been almost unanimous in abandoning the view that mass is the distinguishing feature of matter. Inertia is no longer regarded as a quality confined to matter. The distinguishing feature of matter is now held to be a discontinuous particle structure. Physical fields between material particles are not admitted to be material structures.

Among the small minority of physicists formerly inclined to discard the traditional view that matter consists only of discrete particles was Einstein, who in 1916 wrote: 'We make a distinction hereafter between "gravitational field" and "matter" in this way, that *we denote everything but the gravitational field as "matter"*. Our use of the word therefore includes not only matter in the ordinary sense, but the electromagnetic field as well'* (our italics).

Einstein's tentative enlargement of the concept of matter to cover the electromagnetic field was not accepted, however, by other physicists; nor did Einstein himself continue his revolutionary break with the traditional view that matter consists only of discrete particles. Instead, he revived the concept of the ether in a modified form, presenting it as a physical medium distinct from matter, though not distinct from space.

Einstein formerly applied the term *ether* to 'space with physical qualities', in reverting to the orthodox view that matter consists only of discrete particles. In his *Sidelights on Relativity* (1922), Einstein described as follows his modification of the ether hypothesis as follows:—

'The metrical qualities of the continuum of space-time differ in the environment of different points of space-time, and are particularly conditioned by the matter existing outside of the territory under consideration. This space-time variability of the reciprocal relations of the standards of space and time, or perhaps, the recognition of the fact that "empty space" in its physical relation is neither homogeneous nor isotropic, compelling

* Einstein, The Foundations of the General Theory of Relativity, in *The Principle of Relativity* (1923), p. 143.

us to describe its state by ten functions (the gravitational potentials $G_{\mu\nu}$), has, I think, finally disposed of the view that space is physically empty. But herewith the conception of the ether has again acquired an intelligible content, although this content differs widely from that of the ether of the mechanical undulatory theory of light. *The ether of the general theory of relativity is a medium which is itself devoid of all mechanical and kinematical qualities, but helps to determine mechanical (and electromagnetic) events.*'

'What is fundamentally new in the ether of the general theory of relativity as opposed to the ether of Lorentz consists in this, that the state of the former is at every place determined by connections with matter and the state of the ether in neighbouring places, which are amenable to law in the form of differential equations; whereas the state of Lorentzian ether in the absence of electromagnetic fields is conditioned by nothing outside itself, and is everywhere the same . . . we may say that *according to the general theory of relativity space is endowed with physical qualities*; *in this sense, therefore, there exists an ether.* According to the general theory of relativity, space without ether is unthinkable; *for in such space there not only would be no propagation of light,* but also no possibility of existence for standards of space and time (measuring rods and clocks), nor therefore any space-time intervals in the physical sense. But this ether may not be thought of as endowed with the quality characteristic of ponderable media, as consisting of parts which may be tracked through time. *The idea of motion may not be applied to it*'* (our italics).

The majority of physicists refused to consider any such revival of the ether hypothesis. With the disappearance of that hypothesis, physical fields came to be regarded as structures *of space* — Einstein himself adopting this view.

In 1938, Einstein made the following comment on Kaluza's introduction of a fifth dimension into relativity theory: 'Kaluza's roundabout way of introducing the five dimensional continuum allows us to regard the gravitational and electromagnetic fields *as a unitary space structure*. This result is essential.'† (Our italics).

* Einstein, *Sidelights on Relativity*, pp. 21, 23, 24. Einstein refers here to *mechanical* motion.

† Einstein, On a Generalization of Kaluza's Theory of Electricity, *Annals of Mathematics* (1938), vol. 39, p. 683.

Here we have the hypostasy of space that replaces the ether hypothesis. Space is elevated to the status of an *entity* – a structural entity 'endowed with physical qualities' and 'capable of transmitting electromagnetic radiation'. Instead of recognizing physical fields as material structures whose forms of extension constitute space, physicists assume that space is a non-material entity.

The hypostasy of space into a light-transmitting entity has created insoluble theoretical difficulties, particularly with regard to the wave character of light. Hence the tendency in some quarters to deny the very existence of light waves. W. Wilson, for example, a professor of physics in the University of London, has written:

'It is very improbable that light consists of waves. The fact that it can be propagated through exhausted regions throws doubts on its undulatory nature. For wave propagation some medium is needed, and since the time of the famous experiments of Michelson and Morley and the beautiful relativistic interpretation of them, we have been left without a luminiferous medium.'*

Yet in the Physical Institute of Moscow University, Arkadiev has demonstrated photographically the existence of light waves (short-wave radio). Arkadiev, writes J. G. Crowther in his well-known book, *Soviet Science*, 'can fix the track of the waves along a sheet of white paper'.

'The apparatus consists of a coherer with two electrodes that rest on moistened paper, impregnated with a chemical indicator. The colour of the paper changes owing to electrolytic decomposition of the chemical substance, when the waves fall on the coherer and send a current between the electrodes through the paper. The track of the waves may be followed by putting a large number of small detectors on the paper and joining a series of coloured spots that appear on it.'†

Another method of demonstrating the existence of electromagnetic waves is to place a series of rows of tiny neon lamps in a microwave radio beam. The electromagnetic wave track

* W. Wilson, The Origin and Nature of Wave Mechanics, *Science Progress* (1937–38), vol. 32, p. 209.

† J. G. Crowther, *Soviet Science* (1936), p. 154.

is demonstrated by the lighting up of those particular lamps which receive energy from the waves.

Short stationary electromagnetic waves can be demonstrated by means of an Aron's tube – a long sealed glass tube filled with a gas at low pressure, and containing two parallel wires running end-to-end. High-frequency alternating current through the wires is associated with electromagnetic waves around the wires.

These electromagnetic waves cause the gas within the tube to glow in the shape of a wave train. At the antinodes, the glow extends throughout the whole cross-section of the tube. At the nodes of the wave train, on the other hand, the gas in the tube remains dark.

Electromagnetic waves are not, of course, *mechanical* waves. That is to say, these waves of light do not consist of the motion of material particles. The wave motion of light is *non-mechanical* motion of electric and magnetic field structures. The alternation of these fields, one in front of the other, gives the constant velocity of light.

Because electric and magnetic fields are not composed of particles, they are not regarded by physicists as material structures. And because the wave motion of light is not mechanical wave motion, some physicists deny that there is any such thing as the wave motion of light!

Maxwell's equations formulate the field changes of light, and Einstein's equations formulate the field changes of gravitation, but these field changes are not usually regarded as forms of motion. Traditionally, motion is mechanical motion, and nothing else. From this mechanistic point of view, physical changes which are not mechanical are just – changes!

Theoretical physics thus maintains a false distinction between motion and physical change. This failure to recognize that any physical change consists of various forms of motion creates artificial and insoluble problems.

Some physicists are unable to grasp the very idea of physical continuity, and the non-mechanical motion of field changes. Their whole training buttresses the assumption that everything – including fields – must consist of discrete physical parts, any motion of which must be translatory motion.

W. H. Watson, for example, associate professor of physics

at McGill University in 1938, objected as follows to the idea of a continuous physical structure, intervening between material bodies and acting as a 'medium' for their mutual attraction and repulsion. He wrote:

'The medium's function is to connect one part of space with another, and this appears to be assured because the medium is continuous and any part of the medium touches parts adjacent to it. Clearly, however, *adjacent parts* are not in the same place, *so there still remains the problem of connecting them;* but this is usually overlooked, as is also the thought that the differential coefficients, which express the state of the medium at a point, properly belong to the point *and* its neighbourhood. *Thus the connection of two places close together is essentially the same as the connection of two places far apart*'* (our italics).

A colour-blind person cannot be given an adequate idea of colours; nor can a completely 'particle-minded' physicist be made to realize the physical continuity of a field which does not consist of any physical parts – large or small, close together or far apart.

Taking advantage of theoretical confusion as to the physical 'medium' of light transmission, philosophical idealists have hastened to deny the physical reality of light. James Jeans blandly tells us: 'The theory of relativity washed away the ether. . . . The so-called electric and magnetic forces, then, are not physical realities. . . . They are not even objective, but are subjective mental constructs.' The waves of electromagnetic radiation are 'mere mental constructs and possess no physical existence' – they are 'waves of knowledge.'† This is in line with the views of Eddington, who proclaimed that 'the nature of all reality is spiritual, not material nor a dualism of matter and spirit.'‡

Having already followed Professors Eddington and Jeans into the jungle of their philosophical idealism, we do not propose to repeat the excursion.§

The physical reality of electric and magnetic fields, alternation of which constitutes the propagation of light, is of course beyond dispute, as is the physical reality of the gravitational field.

* W. H. Watson, *On Understanding Physics* (1938), p. 69.
† James Jeans, *Physics and Philosophy* (1942), pp. 134-136.
‡ A. S. Eddington, *New Pathways in Science* (1935), p. 319.
§ R. L. Worrall, *The Outlook of Science* (1946).

The gravitational field, wrote Einstein, 'must be looked upon as real'.* When such a field is created by a rotating body, as is the case of a fast spinning flywheel, the field is likewise 'physically real'† (Weyl), and may even break the wheel which creates it. As for the electromagnetic field, it is for the modern physicist 'as real as the chair in which he sits'.‡ Since Maxwell's time, 'physical reality has been thought of as represented by continuous fields, governed by partial differential equations, and not capable of any mechanical interpretation'.§

Yet although the physical reality of electromagnetic and gravitational fields is fully acknowledged, the fact that such fields are 'not capable of any mechanical interpretation' prevents physicists from admitting their material character. Modern physics is still sufficiently tied to a mechanistic outlook to deny a material character to anything not subject to a mechanical interpretation.

Physics grew out of classical mechanics, i.e. out of the study of corporeal matter and its behaviour, and still clings to the machine-cut philosophy of its youth, in spite of having outgrown it through relativity theory and quantum theory. Any physical structure which does not consist of one or more particles, and does not obey the laws of mechanics, is still treated as something separate and distinct from matter.

Physical fields do not fit into the traditional picture of matter inherited from eighteenth century physics, and are therefore denied a material character.

This arbitrary division of physical reality, into material particles and 'non-material' fields, is responsible for the crises of theory to which modern physics is now chronically subject. The difficulty of co-ordinating particle and field theories is due basically to a false division of physical reality into material and allegedly non-material structures. Across this metaphysical gulf of absolute differentiation, the most daring hypotheses fail to throw a bridge of theoretical consistency.

Only by recognizing particles and fields as two interpenetrating states of matter – corporeal and incorporeal – can

* Einstein, *Sidelight on Relativity*, p. 17.

† H. Weyl, *Space, Time, Matter* (1922), p. 221.

‡ Einstein and Infeld, *The Evolution of Modern Physics*, p. 158.

§ Einstein, Maxwell and Physical Reality, in *James Clerk Maxwell* (1931), p. 71.

theoretical physics escape from otherwise insoluble contradictions.

The current idea that a physical field is a non-material structure (though nevertheless a physical reality!) originated in the philosophical basis adopted by physicists during the early historical development of their science.

During the seventeenth and eighteenth centuries, scientists were mainly occupied with the mechanical motion of corporeal matter, and the mechanical processes of primitive machines. The motion of the planets, the paths of projected and free falling bodies, the working of clocks, pumps and other mechanical contrivances – these were the main objects of study during the early formative period of physics.

With the aid of speculative hypotheses such as that of 'effluvia', and metaphysical beliefs such as that of 'action at a distance', physicists constructed a theoretical system of a purely mechanical character.

In this system, physical reality was regarded as nothing but material bodies influenced by non-material 'forces'.

From this mechanistic point of view, all material structures of the universe are *corporeal* structures; that is to say, structures consisting essentially of one or more material particles.

Put forward originally by Leucippus, Democritus and Epicurus, proclaimed in the first century B.C. by the poet Lucretius, and revived in the seventeenth century by Gassendi, the idea that physical reality consists exclusively of discrete particles in empty space was an ideological broom with which physics swept away the cobwebs of medieval scholasticism. Grasping this idea, physicists were able to explain phenomena in terms of corporeal matter and mechanical motion, instead of wandering blindly in a metaphysical maze of Aristotelian doctrine.

Newtonian physics triumphed by describing certain observed phenomena in simple quantitative terms, so that definite laws of nature could be formulated. For this scientific method an appropriate philosophy was necessary in place of the Aristotelian philosophy which had previously prevailed in European thought. In order to escape from medieval metaphysics, physics needed a mechanistic philosophy in harmony with the dawn of a machine age. Hence the inclusion of Greek atomism in the picture of physical reality presented by Galileo,

Newton, Boyle and others, in opposition to the Aristotelian dogma of the medieval schools.

The idea that matter consists entirely of absolutely discrete particles became firmly established in theoretical physics during the nineteenth century, largely through Dalton's atomic theory, the kinetic theory of gases, and the discovery that the conduction of electricity is the motion of charged particles. To account for the wave motion of light demonstrated by Young and Fresnel, the idea of an imponderable ether distinct from corporeal matter was revived, but the ether too was generally believed to consist of particles.

With Maxwell's equations, however, 'the continuous field appeared side by side with the material particle as the representative of physical reality'.* Growing up more or less independently during the latter half of the nineteenth century, the theory of physical fields founded by Faraday and Maxwell would not fit into the purely particle theory of physics, so that eventually two distinct theoretical systems appeared side by side – the much lamented dualism of particle and field theory. 'This dualism,' writes Einstein, 'although disturbing to any systematic mind, has not yet disappeared.'

Failing to recognize particles and fields as two fundamental states of matter, physicists miss the dialectic unity of these two fundamental states, and are obliged to write: 'We have two realities: matter and field . . . we cannot merge the laws of these two realities either in a particle theory or a purely field physics, for our structure laws, that is Maxwell's laws and the gravitational laws, break down for any great concentrations of energy, or, as we say, where sources of the field, that is electric charges or matter, are present.'†

2. The Interpenetration of Particles and Fields

A physical field is matter in its incorporeal state. A physical particle is matter in its corporeal state. Particles and fields interpenetrate one another to form particle-field systems, such as an atom, a solid body, a living cell, and so on.

* Einstein, in *James Clerk Maxwell* (1931), p. 70.

† Einstein and Infeld, *The Evolution of Physics*, pp. 206, 257.

The unity of the physical world is a dynamic material unity of interpenetrating particles and fields. From this point of view, the Russian physicist J. Frenkel has described matter as 'a collection of interpenetrating dynamical fields, electromagnetic and nuclear, with material particles and bodies forming knot points'.*

These 'knot points', where matter exists in the corporeal state, are characterized by a particular kind of rotatory motion, namely 'spin'.

Material particles are not *absolutely* discrete bodies, as was formerly imagined. The first experiments indicating this fact were those of G. Davisson and L. Germer in America, and of G. P. Thomson in Britain.

Passing a stream of electrons through a thin metal sheet on to a photographic plate, Thomson in 1927 obtained a picture of concentric diffraction rings, demonstrating the wave structure of electrons.

From their observations of electrons reflected from a nickel crystal, Davisson and Germer concluded: 'Our experiments establish the wave nature of moving electrons with the same certainty as the wave nature of X-rays has been established.'

The hypothesis that de Broglie had put forward in 1924 was thus confirmed. Today, in the electron microscope, electron waves instead of light waves are focused to give an image of an object.

A. Dempster was the first to show that protons as well as electrons have a wave type of structure. A microscope using proton waves instead of electron waves has been constructed in France.

Orthodox physicists, rejecting the view that the wave structure of a particle is a material structure, have sought vainly for some non-material 'medium' to account for electron wave phenomena.

'A beam of electrons,' wrote the well-known theoretician W. Heitler, 'must be described "partly" as consisting of a number of individual particles and partly as a wave. . . . *Speculations, as to what the "medium" of the wave is, have proved fruitless*'† (our italics).

Theoretical physics found a serious cause of embarrassment

* J. Frenkel, Problems of Modern Physics, *Nature* (1944), vol. 154, p. 451.

† W. Heitler, *Elementary Wave Mechanics*, p. 7.

in the mathematical treatment of electron waves. This was the discovery that the electron waves of an atom are of more than three spatial dimensions.

Recoiling from the mathematical difficulties of treating a multidimensional electronic wave field as a physical reality, physicists concluded that 'the waves have no physical meaning'.* With considerable relief, they embraced Born's method of treating electron waves as 'waves of probability'.

The wave field of an electron thus became regarded as merely a mathematical fiction – a convenient abstract product of the human mind.

Yet the electron waves to which physicists are loth to grant a material character are as physically real as an atomic bomb. 'Experiments show that the waves have objective reality just as much as the particles – the interference maxima of the waves can be photographed just as well as the cloud-tracts of the particles.'†

Electron wave-lengths can be measured with precision, and vary inversely with the velocities of the electrons. 'An electron moving at the speed of a rifle bullet has a wave-length of about a thousandth of a millimetre.'‡

Moreover, observe what happens when we consider only the wave aspect of an electron, disregarding its particle aspect. *We then find that probability does not come into the picture!* As de Broglie has put it, the wave propagation 'obeys exact laws'.§

These exact laws of electron waves correspond precisely to exact laws of electrons considered as particles. Between wave and particle aspects of electrons and other elementary particles, there are exact quantitative correlations. It is with regard to particle location that uncertainty considerations arise.

Electrons and protons are not the only particles whose 'associated' waves are evidenced under certain circumstances. Atoms and molecules, 'when in the form of beams, behave, as regards their distribution in space, according to the laws of the wave theory'.||

The waves that 'accompany' a material particle are evidently

* G. P. Thomson, *The Atom* (1930), p. 202.

† Max Born, *The Restless Universe* (1935), p. 157.

‡ C. G. Darwin, *The New Conceptions of Matter* (1931), p. 86.

§ L. de Broglie, *Matter and Light* (1939), p. 243.

|| Max Born, *The Restless Universe* (1935), p. 154.

the form of motion which characterizes the dynamic interpenetration of particles and surrounding field structures; for waves 'associated' with a particle are themselves continuous field structures (of another kind), extending indefinitely through the gravitational and electromagnetic fields surrounding the particle.

Under certain circumstances, the wave system of an elementary particle can be annihilated, the particle being destroyed in the creation of electromagnetic fields.

For example, if an electron and a positron collide and fuse, both these particles undergo a process of annihilation, out of which come two photons of light. In other words, the annihilation of the two particles produces radiating electric and magnetic fields, the energy content of which is two quanta.

Conversely, a high energy quantum of light, passing through a system of particles, can be annihilated and give rise to a pair of new particles – an electron and a positron. That is to say, so-called non-material structures, namely the energy-containing electric and magnetic fields of light, can be transformed into material particles.

From the point of view of orthodox physics, matter is annihilated when an electron and a positron are transformed into two quanta of light energy. Conversely, a 'materialization' of energy is said to occur when light is transformed into material particles.

This point of view is a product of the outworn doctrine of classical mechanics, according to which matter consists solely of absolutely inert particles, and energy is an entity separate and distinct from matter. Clinging to this doctrine, physicists will not admit that the energy-containing fields of light are material structures. On the contrary, they commonly describe light as 'radiant energy', in contradistinction to 'inert matter'.

If the material character of radiant energy was recognized, it would not be possible to regard matter as absolutely inert. Matter would then be seen to have an active as well as a passive quality; motivity as well as inertia. Instead of the current view that inert matter is acted upon by non-material energy, matter would be recognized as self-motivated.

All this would conflict with theology, which teaches that something supernatural is ultimately responsible for the activity

of 'inert' matter. Physics therefore retains the assumption that matter is absolutely inert, and that radiant energy is non-material in character.

Modern materialism has no such attachment to theologically inspired assumptions. Defining matter as that which exists independently of thought, we can see that matter is active as well as passive, self-motivated as well as inert. While mass is the quantitative aspect of matter's inertia, energy is the quantitative aspect of matter's motivity.

From our materialist point of view, matter is transformed from its corporeal to its incorporeal state, when particles are annihilated in the creation of radiating electromagnetic fields. Conversely, matter is transformed from its incorporeal to its corporeal state, when radiating fields produce material particles.

Chapter IV

SPACE

I. Extension

What is extension? Our materialist answer to this question begins with a demonstration rather than a definition. Taking up an iron bar or some other body we say bluntly: *here it is!* Pressed for a more comprehensive reply, we point to the existence of physical fields, extending everywhere between material bodies. The spatial structures of fields are forms of the extension of matter.

Faced with demands for detailed information on extension, we send for works on geometry. The quantitative aspect of matter's extension is physical space, the relations of which are investigated by means of applied geometry.

While metaphysicians still weave futile webs of speculation concerning the nature of space, geometry gives us the quantitative relations of extension in terms of spatial dimensions, configuration relations and position possibilities. Geometry analyses extension into spatial elements and relationships, the sum total of which constitutes physical space. The origin of the word 'space' from the Latin *spatio*, meaning '*that* which is drawn out or extended', indicates this basic truth.

Cosmic space – the space demonstrated in the general theory of relativity – is the quantitative aspect of the gravitational field's extension.

The quality of extension is a general mode of existence of matter. Everything is extended in one form or another, and all things are thereby connected spatially with one another, directly or indirectly. The unity of all physical phenomena occurs through the universal quality of extension – and through the quality of motion with which extension is dialectically associated.

Through extension and through motion, every phenomenon is materially connected with another phenomena, every structure with other structures, every state with other states, every process with other processes. Matter is continuous in its quality

of extension, the quantitative aspect of which is physical space.

Physical space in general is the sum total of the quantitative relations of matter's extension, and would remain so if all mathematicians were annihilated along with the rest of the human race. Not so the various types of *mathematical* space which have been elaborated by Euclid, Riemann, Bolyai and Lobachevski.

These mathematical spaces are purely abstract geometrical constructions. Whether any such abstract space corresponds with the actual structure of physical space is in the last resort a question of experience, of human observation, of scientific practice.

Euclidean space was originally constructed mathematically by abstracting from solid bodies the quality of extension, and analysing that quality into spatial relations. The Euclidean point was originally an abstraction from the actual point of a pencil or similar object. The Euclidean straight line is derived historically from the edge of the ruler with which it may be drawn. The Euclidean plane represents the flat surface upon which it is commonly presented. 'A mathematical figure of three dimensions is called a solid body, *corpus solidum*, hence even in Latin a tangible object: it therefore has a name derived from sturdy reality and by no means from the free imagination of the mind.'*

Hence it is not surprising that Euclidean space corresponds with the physical space of solid bodies, and so serves perfectly the needs of architecture, surveying and engineering.

The great step of applying Euclidean geometry to so-called empty space was made by Descartes by means of algebra. Descartes' method of defining spatial positions numerically by means of co-ordinates permitted a geometrical analysis of so-called empty space. Descartes analysed 'empty space' into abstract spatial points, the position of each point being defined by three numbers (co-ordinates). The 'void' of ancient Greek philosophy thus became subject to mathematical treatment.

In modern science, said Einstein, 'the concept of space was introduced by Descartes'.† Descartes, however, did not believe

* Engels, *Anti-Duhring*, p. 49.

† Einstein, The Concept of Space, *Nature* (1930), vol. 125, p. 897.

that there was any such thing as empty space. He regarded the extension of matter as continuous and universal, and space as the dimensions of matter's extension. He wrote:

'There is . . . but one kind of matter in the whole universe, and this we know only by its being extended . . .'*

'By extension we understand whatever has length, breadth and depth, not enquiring whether it be a real body or merely space. . . .'†

'The nature of matter or body does not consist in its being hard, or heavy . . . but solely in the fact that it is a substance extended in length, breadth and depth. . . .'

'There is nothing remaining in the idea of body excepting that it is extended in length, breadth and depth; and this is comprised in our idea of space, not only that which is full of body, but also that which is called a vacuum. . . .'

'As regards a vacuum in the philosophical sense of the word, i.e. a space in which there is no substance, it is evident that such cannot exist, because the extension of space or internal place is not different from that of the body.'‡

While Descartes saw clearly that physical space is the quantitative aspect of matter's extension, modern physicists have not yet grasped this fundamental truth. At the same time, they have been obliged to account for the passage of light between material bodies without postulating any non-material ether as the medium of light transmission. Clinging to their mechanistic tradition that matter consists only of discrete particles, physicists have therefore been obliged to present something else to account for the passage of light.

This 'something' serving as the 'non-material' basis of electromagnetic radiation is now said to be space, which is thus given the status of a physical entity distinct from matter. With this hypostasy of space, physicists strive in vain to give a consistent and comprehensive theoretical picture of the physical world.

Gazing myopically at the space-time continuum of relativity theory, more than one physicist has fallen into the error of supposing this mathematical structure to be a physical entity, distinct from the gravitational field, and enclosing material bodies as a cosmic container.

* Descartes, *A Discourse on Method*, Part 2, xxiii.

† Descartes, *Philosophical Works* (Cambridge University Press, 1911), vol. 1, p.57.

‡ Decartes, *Principles*, Second Part, Principles 4, 11 16.

Hence the illusion that escape from space and time is possible. The writer, Sherwood Taylor, for instance, has put forward the possibility of 'whole stars passing right out of space and time'.

In reality, there is no such thing as empty space separate and distinct from matter. In general, space is the quantitative aspect of matter's extension. Cosmic space is the quantitative aspect of the gravitational field's extension.

Professor B. Hessen, formerly director of the Moscow Institute of Physics, emphasized this modern materialist principle at the Second International Congress of Science and Technology, held in London in 1931, when he said: 'Dialectic materialism considers space as a form of the existence of matter. . . . Empty space divorced from matter is only a logical or mathematical abstraction, the fruit of the activities of our minds, to which no real thing corresponds.'*

Far removed from this modern materialist concept is the obsolete idea that space is the universal void, in which matter is merely a number of discrete particles separated by 'nothingness'. Clinging tenaciously to this ancient error, writers who feed the public on mechanistic interpretations of science ignore the revolutionary implications of relativity theory. Sherwood Taylor, for example, blandly tells us: 'It is common knowledge that all matter is discontinuous – made up of particles separated by empty space . . . we may say that nearly all the bulk or volume of matter is empty space. A table or a brick is nearly all nothingness.'†

Most popular as the alleged location of empty space are the interstellar regions. Between the stars, assert purveyors of physical 'nothingness', there are vast regions of sheer emptiness containing nothing except stray atoms of calcium, sodium and other elements.

Yet throughout the vast interstellar regions known as cosmic space are the perpetually alternating field structures of electromagnetic radiation. Light, visible and invisible, consisting of alternating electric and magnetic fields, is propagated from incandescent stellar bodies as ever expanding spheres of electro-

* B. Hessen, The Social and Economic Roots of Newton's *Principia* in *Science at the Cross Roads* (Kniga, London, 1931).

† F. Sherwood Taylor, *Science Front* (1939), pp. 222, 227.

magnetic radiation. Almost the whole of the known universe is, in the picturesque phase of W. L. Bragg, a 'universe of light'.

The late Professor Eddington attempted to retain the idea of empty space on a mathematical basis. In his *Mathematical Theory of Relativity*, Eddington set out to prove that space can be devoid of fields as well as particles. In particular, he attempted to show the possibility of empty space devoid of the gravitational field. According to the 'new point of view' elaborated by Eddington, 'Einstein's law of gravitation does not impose any limitation on the basal structure of the world. $G_{\mu\nu}$ may vanish or it may not. If it vanishes we say that space is empty; if it does not vanish we say that momentum or energy is present; and our practical test whether space is occupied or not – whether momentum and energy exist there – is the test whether $G_{\mu\nu}$ exists or not'.*

In contrast to such attempts at retaining the false idea of empty space, we have Einstein's insistence that there is no such thing as space devoid of all physical fields and particles. According to relativity physics, space 'is inseparably bound up with the gravitational field,' whose potentials $G_{\mu\nu}$ 'confer upon space its metrical qualities'. And since space without metrical qualities does not exist, 'there can be no part of space without gravitational potentials',† no space apart from the gravitational field.

A comprehensive picture of physical space would show how the extension of the gravitational field is related quantitatively to the various forms of extension of other fields, and to the extension of material particles. This picture, theoretical physics has not been able to present. Not yet have gravitational and electromagnetic fields been adequately comprehended together in one unified field theory.

Einstein's general theory analyses the structure of the gravitational field, presenting its spatio-temporal relations as the space-time continuum. Maxwell's equations, on the other hand, represent the structure of light's electromagnetic fields, but precisely how these interpenetrating fields are related to one another spatially and temporally has not yet been fully formulated.

Nor have physicists yet succeeded in showing how the

* A. S. Eddington, *The Mathematical Theory of Relativity* (1937), p. 120.

† Einstein, *Sidelights on Relativity*, p. 21.

extension of a material body is related dynamically to the extension of surrounding physical fields. Particle and field theories do not at present form one unified system of logical thought.

Physicists have not yet demonstrated the precise spatio-temporal relations between gravitational and electromagnetic fields on the one hand, and electrons, protons, neutrons, etc. on the other. For orthodox physics still sticks to its story that while these particles are material structures, physical fields are non-material. With this false theoretical dichotomy between particles and fields, the way in which they are connected spatially and temporally is inevitably obscure.

How can modern materialism shed light on this situation? In the first place, by emphasizing the material character of physical fields, which are structures of matter in its incorporeal state. Secondly, by pointing out that particles and fields interpenetrate one another to form an infinite variety of material particle-field systems. Thirdly, by showing that the quantitative aspect of any physical system's extension is the space of that system.

II. Size.

Sophisticated speech has dimmed our appreciation of the quality of extension, although it is a universal mode of existence of matter. *Distance*, *size* and *shape* are spatial terms which have been cut adrift, so to speak, from their material origin, namely the quality of extension. Yet a physical distance is essentially a one-dimensional quality of extension, while the shape of an object is the external form of its extension. As for the size of an object, it is the amount of extension of the object as a whole, relative to the length of a measuring rod or some other quantity of extension.

How do we determine the size of an object? In the first place, by using our senses as physiological instruments for measuring extension. Crude sensory measurements of extension, made by visual, muscular and cutaneous sense-organs, preceded by a good many thousand years our more exact measurements made with the help of standard measuring rods and other apparatus. We judge the size of an elephant by using our eyes and comparing its extension quantitatively with that of a mouse, a man, a tree,

etc. Measuring extension physiologically in this way, we learn that objects are bigger or smaller than one another by means of comparison.

It was pointed out by Helmholz that if all objects became bigger or smaller, instantaneously and proportionately, we could be unaware of the change! Things are larger or smaller *in relation to one another*. The size of a structure is the amount of its extension relative to some other quantity of extension, not to the amount of some hypothetically independent space which the structure 'occupies'.

The use of measuring rods as standard units of extension permits us to give numerical values to the relative sizes of different objects. These numerical values are affected by the relative motion of measuring rod and object measured, in accordance with the FitzGerald-Lorentz contraction. That is, the constancy of the velocity of light makes measurements of distance and size dependent upon the kinematic conditions of measurement.

This does not mean that objects actually change in size or shape with motion. Spatial relationships exist independently of the human measurements which give them numerical values. It is these numerical values, not the spatial relations themselves, which change with motion relative to the measuring rod concerned. Anyone who manages to travel with the speed of light will not alter the fact that elephants are bigger than mice. In short, the FitzGerald-Lorentz contraction is an apparent contraction, not an actual physical contraction.

Close attention to what we do with measuring rods leads to a materialist understanding of the nature of physical space.

Every physical measurement is a measurement of some physical quality – some mode of existence or mode of behaviour of matter. A physical quality is a form, or state, or process, or tendency of matter, the quantitative aspect of which is defined numerically by means of measurement. When we measure inertia or elasticity or any other physical quality, we define some quantity of that quality in terms of units. Measuring inertia for instance, we define a quantity of inertia in terms of units of mass, which are unit quantities of inertia.

Measuring extension with a standard rod, we define amounts

of that physical quality in terms of spatial units, which are unit quantities of extension. Using measuring rods – either real or ideal – we analyse extension quantitatively into spatial relations, the sum total of which is space. Physical space is the quantitative aspect of matter's extension, demonstrated mathematically by means of certain units of extension, namely measuring rods.

The measuring rod most commonly used is the metre rod – a bar of platinum-iridium alloy kept in France. The marked length of this rod was originally designed to equal a certain small fraction of the shortest distance on the earth's surface between the North Pole and the Equator, the line passing through Paris. Not being quite equal to this, the standard metre rod is in fact a metal rod of arbitrary length.

Earlier physical structures serving as units of extension included the chain – an actual chain composed of one hundred iron rods joined end-to-end. Introduced in 1624 by the English surveyor Gunter, it must have been a weighty reminder of the material basis of spatial units! Equally concrete in its origin, the furlong was originally the 'furrow-long', which was the average length of furrow a team of oxen could economically plough without pausing for breath.

In 1923, the International Committee on Weights and Measures decided to authorize experiments with a view to adopting a new physical structure as a standard unit of extension. It was suggested that the wave-length of light from incandescent cadmium, giving a red line in the spectrum, should be the new unit.

Extension may of course be measured in spatio-temporal units instead of purely spatial units. The cosmic extension of the gravitational field is measured in light years, one light-year being the distance travelled by a ray of light during one year.

Our general concept of size is based upon the extension of solid bodies, including measuring rods. This concept receives some rude shocks when applied to the extension of atomic particles and physical fields. The extension of a solid body is more or less sharply limited peripherally by its surface, this boundary giving the body a definite size.

Very different is the extension of an atom, which has no surface. An atom's periphery is a dynamic structure of electrons,

extending nebulously as a 'cloud', and dynamically in the form of multidimensional waves.

Since the extension of an atom blends dynamically with the extension of surrounding fields, an atom 'has no rigid boundary'. Hence, 'it is impossible to draw a sphere around the nucleus, which just contains the electrons bound to it'.*

'It is very difficult,' wrote the physicist P. Debye, 'and the difficulty is immensely increased by our new conceptions of wave mechanics, to say exactly what we mean by the outside of an atom.'

The cloud of electrons which moves within the field of an atomic nucleus has definite size only in relation to the electron clouds of adjacent atoms. Attempts to define the size of a single electron have created insoluble theoretical contradictions.

The charge of an electron can be regarded as distributed throughout a small sphere, with a radius of the order of 10^{-13} centimetres. But experiment and theory both render untenable this view that the electron is a small sharply defined sphere.

On the other hand, the idea that the charge of an electron is concentrated in a dimensionless spatial point is likewise untenable, since it involves the conclusion that the self-energy of the electron is infinite!†

To quote the Russian physicist Frenkel: 'The structure of the electron has been tackled hitherto from two angles, one treating it as a point charge and the other as if it had extension. Along both avenues of approach insuperable difficulties have been encountered.'‡

These insuperable difficulties are created by physicists themselves, in attempting to define the extension of a particle which extends indefinitely. The only way to dismiss these difficulties is to describe the size of an electron in terms of its dynamic interpenetration with surrounding fields.

3. Shape and Structure

Newton, it is said, was led to formulate his law of gravity by seeing an apple fall to the ground. James Watt is alleged to

* W. L. Bragg, *Atomic Structure of Minerals* (1937), p. 30.

† A. Pais, *Physical Review* (1945), vol. 68, p. 227.

‡ J. Frenkel, *Nature*, October 7, 1944, p. 454.

have arrived at his understanding of steam power by watching a kettle boil. These apocryphal stories of discovery serve to remind us that the most familiar things can be gateways to profound knowledge.

Nothing is more familiar than the shapes of common objects, yet a systematic consideration of common shapes must have given birth to the beginnings of geometry in ancient times.

The shape of a thing is the external form of its extension. Since an object's shape is constituted by the external limits of its extension, the shape may be reproduced by the object's immediate environment. Sand thus reproduces the shape of a foot in the way that Robinson Crusoe found so disturbing.

The shape of a thing, unlike its size, is not a quantitative relationship necessarily involving some other object. The mutual spatial relations of an object's own extension constitute its shape. A body whose shape is a cube, for example, is an object whose six sides are all equal in area *to one another*.

The shape of a body is a particular form of extension, and as such it is a physical quality. Geometry permits us to break up this quality abstractly into its component spatial relations – into specific angles, curves and so on. Euclid's predecessors – the 'forgotten men' of geometry – were the first to give systematic descriptions of elementary spatial relations in this way.

But these ancient mathematicians were far from being the first to abstract forms of extension from nature. Long before mathematicians began to analyse extension into spatial relations, men were portraying various forms of extension of living animals. Long before geometricians first considered such shapes as circles, triangles, squares and so on, cavemen of the palaeolithic age were abstracting in carvings and drawings the shapes of bear, bison and horses. Immortalized on the walls of prehistoric caves are man's first pictorial abstractions from nature of various forms of extension. The ancient discovery of human power to abstract extension pictorially from other physical qualities was the very genesis of graphic art.

Every form of extension is associated with various forms of motion, so that every structure is in some respects a process. While stable structures such as igneous rocks and fossils have preserved their forms of extension intact and constant for long

periods of time, every structure is subject to modification or destruction. In the long run, everything changes.

Only a very one-sided picture of physical reality is given by representing extension apart from motion. All matter is in motion as well as extended. A wave on the surface of the sea, for example, is not only a form of extension; it is also a form of motion.

In the case of an atom, extension and motion are considered conjointly (along with inertia), so that numerical values for space and time (and mass) form an abstract multidimensional construction termed 'configuration space'.

Hermann Grassmann (1804-1877) was the first to publish a book showing that space may be of more than three dimensions. Grassmann, like Descartes, took the view that space is the quantitative aspect of matter's extension. But whereas Descartes arbitrarily limited extension to three spatial dimensions, Grassmann developed the idea of extension with any number of dimensions.

Before Einstein, mathematicians were almost unanimous in believing that 'empty' physical space, like the space of a solid body, was necessarily Euclidean in character. Those who thought otherwise were Gauss, Riemann, Lobachevski and Bolyai.

Today we know that 'empty' space – the space of the gravitational field – is non-Euclidean. While Euclidean geometry does give a correct analysis of the macroscopic extension of solid bodies, it does not represent correctly the form of extension of the gravitational field.

Einstein was able to demonstrate that the masses and velocities of material bodies determine the geometrical character of space, or space-time; and also, that the geometrical character of space-time determines the motion of free-moving bodies. The general theory of relativity 'derived the laws of motion from the geometrical structure of space, or rather of space-time, thus uniting geometry and physics in a new intimacy'.*

Already on the horizon of science there appears the beginning of a similar intimacy between geometry and biology. W. I. Vernadsky, member of the Academy of Sciences of the U.S.S.R., has outlined the application of non-Euclidean geometry to the structure of living matter. The following summary of Vernad-

* Einstein, *Nature* (1930), vol. 125, p. 897.

sky's analysis is given by the *Medica' Journal of Australia*:

'The intrinsic quality of the space within a living organism is, we are told, distinguished by polar vectors and is marked by symmetries characteristic of Riemann's geometry. There are no straight lines and no plane surfaces in life. Above all there is a marked dextrality or sinistrality in life spaces conditioning the exclusive choice of an optical isomer. . . . Time in the realm of the living is not the geometric time of Minkowski, nor is it the time of mechanics and theoretical physics as with Newton. . . . In Vernadsky's opinion . . . when we come to biology we strike complexities which demand the creation of a new geometry far more involved than those of Lobachevski and Riemann.'*

In analysing geometrically the structure of any physical system, we describe the extension of that system in terms of spatial relations. A geometrical analysis of a material structure thus gives us a 'close-up' of one of the most fundamental qualities of matter, namely the universal quality of extension. Here we are at the very heart of natural phenomena, the dynamics of which entail also a consideration of motion. Certain eminent scientists with a taste for mysticism, however, are fond of postulating something 'beyond' scientific knowledge.

The well-known astronomer Spencer Jones, for example, wrote of the late Professor Eddington: 'He showed that in dealing with the universe, science is confined to investigating its structure, it can tell us nothing of the nature of that which possesses that structure.'†

Giving free reign to their philosophical imagination, these agnostics first postulate an unknown 'something' behind physical structures, and then demurely announce that the structures they are investigating are merely – structures! Behind the structure of the universe is the 'something' whose nature allegedly defies scientific investigation. The physical qualities of nature are thus reduced to the status of mere appearances, under cover of which are realities as unknowable as they are unknown!

Such metaphysical make-believe loses its reputation in the light of modern materialism, which is based upon the main

* W. I. Vernadsky, Problems of Biochemistry, *Transactions of the Connecticut Academy of Arts and Sciences*, June 1944, p. 483; summarized in *The Medical Journal of Australia*, January 6, 1945.

† H. Spencer Jones, *Nature*, December 16, 1944, p. 759.

experimental findings of science. Scientific investigations of nature reveal an endless variety of physical structures, states and processes. As a whole, each structure, state or process is a physical quality; that is to say, a mode of existence or mode of behaviour of matter.

Modern materialism presents matter as the sum total of all physical qualities – of all physical structures, states, processes and tendencies. Modern materialists do not postulate an all-pervading 'something' whose unknown nature gives rise to physical phenomena. Matter is not a homogeneous passive substance which is somehow moulded into structural forms by non-material agencies. Matter is the sum total of all physical structures, and all the physical processes which constitute change. Matter is heterogeneous in its dynamic multiformity; self-motivated in its endless activity.

This modern view of matter, contrasted with the old view that matter is essentially formless substance, has been well put by C. S. Sherrington – one of the founders of modern neurology. Referring to Jean Fernel as a typical sixteenth century holder of the old view of matter, Sherrington says:

'Matter was for him and his time an inert substratum. Today it is a system of rushing units; a hive of self-maintained activity; a population of electric charges, spinning, attracting, repelling, circling a million million times a second. . . . The inert substance of Fernel, even where most static, is today changed to equilibria of torrents of movement. Its very continuity is continuity of change. Instead of separating form from matter, form and matter become inseparable – one and the same motion. It is so wherever matter is, in rock, in tree, or man.'*

How close is this vivid expression of modern materialism to the view of Diderot, who said: 'All is in perpetual flux. . . . I see everything in action and reaction, everything destroying itself under one form, recomposing itself under another form; sublimations, dissolutions, combinations of all kinds, phenomena incompatible with the homogeneity of matter; and therefore I concluded that matter is heterogeneous, that an infinity of divers elements exist in nature.'†

* C. S. Sherrington, *Man on his Nature* (1940), p. 23.

† *Diderot, Interpreter of Nature* (J. Stewart and J. Kemp translation, 1937), pp. 77, 131.

Between the outlook of Diderot and the insight of Sherrington there is scarcely a hair's breadth of difference, despite the two centuries separating the French philosopher from the British scientist. Both are brilliant exponents of material dialectics.

Chapter V

MOTION

The main difficulties of theoretical physics arise from false assumptions concerning matter and motion. Matter is still said to consist solely of particles. Motion is generally held to be the translatory motion of particles or larger bodies.

Rotatory motion is regarded as a special case of translatory motion, the classical definition of which is change of position of a material body.

'Motion', wrote P. G. Tait,* a nineteenth century physicist, 'is mere change of position.' Generally speaking, this view still prevails in modern physics.

Now only a discrete structure can have a physical position. We are able to determine *where* a body is because it is 'marked out' from surrounding fields by a certain discreteness of structure. We can say that a body is *there* because it is relatively discontinuous with its surroundings.

The position of a discrete physical structure is defined mathematically by co-ordinates, which are position-defining numbers. In classical mechanics, the position of a body is defined numerically by co-ordinates which refer to some other body – some particular 'body of reference'.

In relativity physics, positions are defined numerically by Gaussian co-ordinates, which do not refer to any particular body. But these Gaussian co-ordinates have in themselves no physical significance. 'A real significance attaches only to the Riemannian metric, not to the co-ordinates or their differences.'†

For calculation purposes, we can of course use co-ordinates to define numerically a 'point of space', or some abstractly outlined region of a physical field. But such co-ordinates are merely numbers, and do not represent any *physical* position.

* P. G. Tait, *Lectures on Some Recent Advances in Physical Science* (1885), p. 14.

† Einstein, The Origin of the General Theory of Relativity, *University of Glasgow Lecture*, June 30, 1933.

Relativity theory analyses the gravitational field into points of space or space-time. Let us repeat: these points are not physical realities; there are no such points in the physical world.

Numerical definitions of spatial points, or spatio-temporal points, or abstractly differentiated regions of a field, do not represent physical reality. 'It is neither the point in space, nor the instant in time, at which something happens that has physical reality, but only the event itself.'*

As far as classical mechanics is concerned, a physical position is a position *of rest* of a material body. The term *position* means a static condition, as far as physical reality is concerned.

The idea that a body's translatory motion is a series of infinitely close positions of rest is a fallacy, however, as Zeno showed in his famous paradoxes.

Mathematical teaching asserts that translatory motion is the change of a body from one position of rest to another. Instead of this teaching being given as the convenient fiction that it is, students are usually asked to swallow it as gospel truth!

Engineering students are sometimes taught that the lowest part of the wheel of a moving vehicle is actually in a position of rest for a moment, while in contact with the ground!

All this is merely mathematical make-believe. To quote T. Dantzig, a somewhat exceptional professor of mathematics:

'Our senses perceive motion as something individual, uninterrupted. The very act of resolving motion into elements results in the destruction of the continuity which we have resolved to preserve. For the purpose of number, it is necessary to regard the line as a succession of infinitesimal resting-stations, and this is repugnant to the very idea of motion conceived by us as direct opposite of rest.'†

The difference between continuous motion as we perceive it, and 'the mathematical fiction masquerading under the same name', has been clearly brought out by Dantzig, who continues (as if he were Zeno speaking):

'You say that just as space consists of an infinity of continuous points, so time is but an infinite collection of contiguous instants? Good! Consider, then, an arrow in its flight. At any instant its extremity occupies a definite point in its path. Now,

* Einstein *The Meaning of Relativity* (1922), p. 33.

† T. Dantzig, *Number, The Language of Science* (1930), p. 140.

while *occupying this position* it must be *at rest* there. But how can a point be motionless and yet in movement at the same time?'

'The reply of the mathematician', continues Dantzig, 'ignores Zeno's paradoxes by referring to a *mathematical* definition of motion. Motion is defined as a correspondence (a "function") between position and time.'

This definition mistakes a mathematical treatment of motion for the actual motion itself. Ignoring the physical continuity of actual motion, mathematicians present their convenient fiction that motion is essentially a series of discontinuous positions of rest, *as if the fiction was the reality!*

To quote Professor Dantzig again (p. 127): 'Mathematical motion is just an infinite succession of states of rest, i.e. mathematics reduces dynamics to a branch of statics . . . motion made up of motionless states is no more nor less absurd than a length made up of extensionless points, or a time made up of durationless instants.'

'True this abstraction is not even the skeleton of the real motion as perceived by our senses! When we see a ball in flight we perceive the motion as a whole and not as a succession of infinitesimal jumps.'

As Aristotle pointed out long ago, the fallacy demonstrated by Zeno's paradoxes is the assumption that physical motion is actually a body's transference from one position of rest to another.

In reality, translatory motion is a *continuous* change of the spatial relations between different bodies. While two bodies are in motion relative to one another, they are never in a state of relative rest – never in positions of rest with reference to one another. Only on paper, only in the abstractions of mathematical description, is a body's translatory motion a series of discontinuous 'jumps' from one position of rest to another.

The mathematical analysis of translatory motion into a series of positions of rest (infinitely close to one another) is of course a very convenient procedure, to say the least of it. Classical mechanics depends in fact on this mathematical description of translatory motion, which gives an exact numerical definition of a body's position at any instant, as well as an exact statement of the body's rate of change of position.

Classical mechanics, however, deals primarily with the motion of solid bodies, such as wheels, vehicles, bullets, planets and so on. And solid bodies are definitely discrete physical structures, sharply defined physically from surrounding field structures.

Moreover, solid bodies *can* have physical positions of rest relative to one another. The spare wheel of a moving automobile, for example, is in motion relative to the road, but does have a position of rest with reference to the vehicle itself.

Hence the translatory motion of a solid body can be treated mathematically *as if it were* a series of infinitely close positions of rest, without breaking completely with physical reality.

Very different is the situation where a moving object has not a highly discrete structure, and is never at rest relative to any body of reference. This is the situation within an atom, where orbital electrons surround a central nucleus.

An electron's extension is not limited peripherally by a structural boundary, and lacks the discreteness of solid bodies. Within an atom, an electron's diffuse and dynamic form of extension blends structurally with the atom as a whole.

Physicists have ceased to regard an electron as an absolutely discrete particle. They no longer picture an electron within an atom as a discrete body, revolving around the nucleus in an orbit which is divisible numerically into a series of positions of rest.

Classical mechanics with its key concept of *position* has been abandoned in dealing with the dynamics of atomic structure. The motion of electrons within an atom is now represented by the non-mechanical concepts of wave 'mechanics', developed by de Broglie, Heisenberg, Schrödinger, Pauli, Dirac, Born and others.

The structurally diffuse electrons around an atomic nucleus are now described as an electron 'cloud'. To each electron are ascribed certain spatial 'haunts', at any numerically defined position of which there is a probability of an electron particle being present at a given instant. To quote Max Planck, the founder of the quantum theory from which wave-mechanics has been developed:

'The revolution of an electron around the nucleus is not so much like the movement of a planet around the sun, as like the rotation of a symmetrical ring upon its centre, so that the ring as a whole retains the same position in space; thus there

is no physical meaning in referring to the local position of the electron at any instant. . . . Wave mechanics possesses only one means of defining the position of a particle, or more generally the position of a definite point in configuration space; this consists in superimposing a group of individual waves of the system, in such a way that their wave-functions cancel each other by interference everywhere within configuration space, and intensify each other only at the one point in question. In this case the probability of all the other configuration points would be zero, and would be equal to 1 only for the one point in question.'*

Even then, infinitely small wave-lengths would be necessary to isolate this point completely.

Relativity theory too has moved away from the classical concept of position. Efforts to create a unified field theory, covering electromagnetic as well as gravitational phenomena, have passed beyond the idea of the single abstract point of space, defined by three numbers representing three spatial dimensions.

Commenting on Kaluza's attempt to formulate a unified field theory, Einstein has written: 'If Kaluza's attempt is a real step forward then it is because of the introduction of the five dimensional space (periodic with respect to one dimension). A point P of the physical space will, therefore, be represented by an infinite number of points P, P', P''. . . . '†

One thing remains certain: there are no physical positions of a field itself – a field devoid of particles. For a field does not consist of material bodies, and only a material body can have a physical position.

A field is a continuous structure that does not consist of parts – does not consist of particles and other bodies. And according to the principle of relativity, only a material body can be in mechanical motion or in a position of rest. That is to say, there is no motion of a body relative to a surrounding field.

Supposing, however, we disregard the principle of relativity. Supposing we try to detect experimentally a body's motion relative to a surrounding field. What do we find? We find that observations and experiments show no translatory motion of a body relative to continuous fields. And this is in accord with the principle of relativity.

* Max Planck. *The Universe in the Light of Modern Physics* (1937), pp. 32, 36.

† A. Einstein and P. Bergmann, *Annals of Mathematics* (1938), vol. 39, p. 683.

Consider, for example, an experimental attempt to detect friction between a body and a surrounding field.

Theory tells us that friction is an expression of dynamic physical relations between material bodies. It is not surprising, therefore, that experiments fail to show any friction between a moving body and a surrounding field. For the field is continuous; does not consist of particles; is not composed of material bodies.

The climax of all attempts to detect translatory motion relative to fields was the Michelson-Morley experiment. In effect, this experiment was an effort to demonstrate translatory motion of the earth relative to the electromagnetic fields of light.

It is true that Michelson and Morley, following a suggestion by Clerk Maxwell, were trying to detect motion of the relative to a surrounding 'ether'. But this ether was a purely hypothetical medium, postulated by physicists to fill a gap in their fundamental theory.

In reality, the Michelson-Morley experiment was a test of whether the earth moves in its orbit, relative to radiating electric and magnetic fields.

As a result of the experiment, Einstein concluded that the velocity of light is constant, irrespective of the material body to which the motion of light is referred. In other words, Einstein concluded that a body does not undergo translatory motion relative to radiating electromagnetic fields.

Later, Einstein formulated his general theory, which excluded the idea that a body can move relative to the gravitational field surrounding it.

The principle of relativity was thus confirmed. Maintaining the principle, modern physics shows that a material body does not move relative to a continuous surrounding field. Simply because the surrounding field *is* continuous.

Modern physics, however, adds that a continuous field is not a material structure, since it does not consist of particles. In accordance with this assumption, physicists assert that fields are structures 'of space', or ' of space-time'.

Such an assertion creates insoluble theoretical contradictions. These contradictions can be avoided by recognizing that physical fields are continuous material structures – structures of matter in its incorporeal state.

From this point of view, the principle of relativity retains its validity, and can be stated as follows: *there is no translatory motion between a material body and a material field surrounding it, because the field is a continuous structure, not composed of other bodies.*

This means that a field in contrast to a particle is neither at rest nor in mechanical motion. The principle of relativity excludes the idea that a gravitational, electric or magnetic field (in contrast to a particle) can be in a state of rest or translatory motion.

The hypothetical ether of pre-relativity physics was thought to be either in translatory motion, or – as Lorentz imagined – mechanically motionless. Neither alternative proved tenable. Hence the final abandonment of the ether hypothesis.

With the hypothesis of a mechanical ether out of the way, we are not compelled to attribute mechanical rest or motion to a physical field.

A gravitational, electric or magnetic field surrounding a material body is – mechanically speaking – neither moving nor motionless. Such a field, though material, is a non-corporeal structure. Therefore – to paraphrase Einstein – the idea of mechanical motion may not be applied to it, nor may the idea of mechanical rest.

According to the current assumptions of theoretical physics, the only kind of motion is the mechanical motion of corporeal structures – of material particles or other bodies.

Physicists do not recognize structural changes of the gravitational field as a form of motion; nor the formation and extinction of an electric or a magnetic field; nor the waves which 'accompany' electrons and other particles.

Motion is nothing but mechanical motion – the translatory or rotary motion of material bodies – as far as current theoretical physics is concerned.

From our materialist standpoint, however, we can see that *every physical change consists of one or more forms of motion.*

For example, when an electric radiator is switched on, the changes which then occur include the translatory motion of electrons passing through the coiled wire of the radiator, the non-mechanical motion of the electron waves, the oscillatory atomic motion of the heated wire, and the wave motion of the wire's electromagnetic radiation.

Even such a comparatively simple phenomenon as the translatory motion of a solid body comprises non-mechanical forms of motion. The motion of the moon around the earth, for instance, involves non-mechanical motion of the gravitational field surrounding the earth. And this in turn involves the mechanical motion of the earth's tides.

Incidentally, an oscillating body is thought to radiate non-mechanical waves of the gravitational field, although these gravitational waves have not yet been demonstrated experimentally.

Motion, like extension, is a universal mode of existence of matter. Everything is in motion and everything is extended.

We measure quantities of extension with measuring rods and quantities of motion with clocks. We thereby define quantities of extension and motion numerically, in terms of space and time.

The distance between any two physical positions, A and B, is a linear quantity of extension. This quantity of extension can be defined numerically in terms of inches, feet or other spatial units, by measuring it with a standard rod.

A body's change of position from A to B is a quantity of translatory motion. This quantity of motion can be defined numerically in terms of seconds, minutes or other temporal units, by measuring it with a standard clock.

The linear quantity of extension between A and B, relative to the quantity of motion of the body between A and B, is the body's velocity. In other words, velocity is a relationship of distance to time.

The fact that velocity is a relationship of *distance* to time is the fundamental reason for Heisenberg's principle of indeterminacy. A number of physicists – and others – have given a philosophical twist to this principle, in a concerted attack on the concept of causality.

Heisenberg's principle of indeterminacy as a bare statement of fact is of course correct. The principle states: it is impossible to give equally exact numerical definitions of the velocity *and* the position of a particle at any given instant.

Now every *observed* velocity is a relationship of a *finite distance* to a *finite period* of time. As Dirac has pointed out, 'observed velocities are always average velocities through appreciable

time intervals'.* Observation, therefore, cannot give an exact numerical value to the particle's velocity *at a given instant*, since an *instant* is not a finite period of time; is not an appreciable time interval.

If, therefore, we give an exact numerical value to a particle's velocity *at a given instant*, we are departing from the facts of observation and entering the make-believe realm of mathematical infinity. Even so, no contradiction appears, provided we do not attempt to define the particle's position exactly, at that instant.

If, however, we seek to define the particle's velocity *and* position equally exactly, at a particular instant, a contradiction does appear. For it then becomes clear that what we seek to do is impossible.

In 1926, Heisenberg gave a quantitative expression to this impossibility, from mathematical calculations based on experimental data. The same impossibility can be given a qualitative expression, from reasoning based on more general human experience.

Realizing, with Dirac, that an *observed* velocity is necessarily a ratio of a *finite* distance to a *finite* period of time, we can understand that *it is impossible to observe a particle's velocity at a given instant*. For an instant is an infinitely small and therefore unobservable time interval.

As regards position, a moving particle can of course be attributed *mathematically* with a numerically exact position at a given instant. But an exact numerical value for a moving particle's position at a particular instant is not an *observed* value. For only in abstract thought does a particle's motion consist of a series of positions. And only in the abstractions of mathematics does a clock's motion consist of a series of instants.

In reality, the motion of a particle is a *continuous* change, not a discontinuous passage from one position to another. And the velocity of a moving particle can only be observed by measuring a finite distance and a finite period of time.

In short, it is impossible to *observe* a particle's velocity at a given instant. And the idea that a moving particle can actually occupy an exact position is merely a convenient mathematical fiction.

* P. A. M. Dirac, *The Principles of Quantum Mechanics* (1935), p. 260.

This latter fact, which was known to ancient Greek thinkers, has been ignored by modern physicists. Hence the illusion that a moving particle has an exact velocity and an exact position at a particular instant.

Suffering from this illusion, physicists were surprised to learn from Heisenberg that they could not give equally exact numerical definitions of the velocity and position of a moving particle at a given instant. They have not yet traced their surprise to the false belief that the velocity of a moving particle can actually be observed at a given instant.

Instead, physicists have naïvely concentrated on experimental obstacles to what they formerly believed was an experimental possibility.

Believing incorrectly that a moving particle actually passes discontinuously from one position to another, physicists had assumed that equally exact values for velocity and position at a given instant could be attributed to a moving particle, *without any error*. When Heisenberg showed this assumption to be false, a veritable dust storm of bad philosophy and theoretical confusion was created.

Blinded by confusion created by their own false assumptions, many physicists have interpreted Heisenberg's principle as a blow to the idea that causality prevails in the physical world.

As far as causality is concerned, Heisenberg's principle merely drew attention to limitations of human ability to predict events. Whereas nineteenth century physicists knew no theoretical limits to human prediction, physicists are now aware of such limits.

Heisenberg's principle of indeterminacy gives no justification for assertions that the principle of causality has been overthrown, and that all is therefore determined by pure chance.

Heisenberg's principle does not mean that there are no causal laws of nature, or that certainty is a myth. The principle of indeterminacy does not affect, for example, the causal laws of attraction of positive and negative electrical charges. Nor the certainty that two atoms of hydrogen, combining with one molecule of oxygen, will make one molecule of water, in prevailing terrestrial circumstances.

Modern theoretical physics has not established indeterminism, whatever the impression conveyed by physicists and mathematicians with a leaning towards philosophy. Contrary to the nonsense written by Borel, Eddington, Bertrand Russell and others, miraculous exceptions to causal laws are not liable to occur through the operation of statistical laws.

Statistical laws, like causal laws, have their own limits of operation. These limits, which are qualitative in character, make impossible such fantastic suppositions as the idea that chance would ultimately make a dozen monkeys write all the books in the British Museum, if they strummed on typewriters for a sufficiently long period of time.

Such ideas, which have been put forward as the 'latest thing' in theoretical physics, arise from the false conclusions which have been drawn from Heisenberg's principle of indeterminacy. Suddenly catching sight of unavoidable limitations of human measurement, various writers on physics – including more than one physicist – have embraced a philosophy of indeterminism. Much confusion has followed their attempts to justify stories of miracles with a philosophy of indeterminism.

We must now touch briefly on another source of confusion concerning motion.

The momentum of a body is the product of its mass and its velocity. Textbook physics tells us that this product is the quantity of motion of the body.

Velocity, however, is a quantity which involves extension as well as motion, space as well as time. When we consider velocity, we are considering a distance, as well as the motion of a body in relation to that distance.

Measured with a clock, a quantity of a body's motion is defined numerically in terms of time. The distance 'covered' by the body during that time is defined numerically by a measurement made with a standard rod.

The velocity of the body is a ratio – the ratio of the distance 'covered' to the time 'taken'.

Velocity is thus not merely quantity of motion, but a ratio which includes quantity of motion as one of its two components.

The other quantity involved in momentum, namely mass, does not belong to kinematics – the science of 'pure' motion.

Mass takes us beyond the study of motion proper, to a consideration of a non-kinematical quality, namely inertia.

It is confusing, therefore, to talk about momentum as 'quantity of motion'. Time, not momentum, is the quantitative aspect of motion.

Chapter VI

TIME

1. The End of an Illusion.

Confronted with the question: What is time? A modern working physicist may pull out his watch and answer briefly: Here it is! This clock, however, is a measuring instrument, and hence arises the further question: What does a clock measure?

If our physicist replies that clocks measure time, he may thereby indicate that time is something distinct from motion, though measurable by means of the motion of clocks. This leaves the nature of time an open question for fruitless metaphysical discussion.

M. F. Cleugh, for example, asks: 'Time is measured by means of motion; but motion presupposes the idea of time: how can we explain the circularity?' The same author continues: 'Physics is concerned with the measurement of time, rather than with the essentially metaphysical question as to its nature.'* Thus we arrive at metaphysics through a circular question of the type, 'which came first, the chicken or the egg?'

This pitfall of metaphysics was dug many centuries ago by Plotinus, who wrote: 'Motion time cannot be . . . since motion takes place in time.' Quoting this hoary fallacy, J. A. Gunn adds approvingly: 'Long ago Plotinus urged that problems of *measurement* would give no clue to the *nature* of time. This is profoundly true'!†

Avoiding this pitfall of metaphysics, our physicist may say that clocks measure motion. This materialist reply is buttressed by the facts of scientific and everyday experience, and was well known in Greek philosophy.

Aristotle at one point in his *Physics* states explicitly that 'time is but an aspect of motion',‡ and also writes 'as if it were a common opinion that time is motion'.§

* M. F. Cleugh, *Time* (1937), p. 8.

† J. A. Gunn, *The Problem of Time* (1929), p. 173.

‡ Aristotle, *Physics*, Book VIII, chapter I.

§ H. Cherniss, *Aristotle's Criticism of Presocratic Philosophy* (1935), p. 217.

The main opposition to this materialist opinion was developed originally by Plato, who in the *Timæus* described time as a product of divine intelligence. Time, according to Plato, is an independent entity distinct from motion, though inseparable from the periodic motion by which it is measured.

Time is presented in Plato's *Parmenides* as something which is advancing, thus originating 'the current conception of time as "the overflowing" stream, itself advancing and carrying temporal things with it'.* How Plato's concept of time eventually came to be adopted by Newton is an interesting page in the history of ideas.

Plotinus, who founded the school of neo-Platonism in Alexandria in the third century A.D., described time as the spiritual activity of a world 'soul', in which 'all movement and rest exist smoothly and in order'. 'Time', said Plotinus, 'brings into being night and day', so that 'we have thus a measure of time'.†

Neo-Platonism, embodying this doctrine of the nature of time, was recast by Porphyry in Athens in the fourth century, later systematized by Proclus in the fifth century, and finally introduced into Christian theology by St. Augustine, Boetius and other writers.

During the Middle Ages, the doctrines of neo-Platonism were fostered in the Florentine Academy. In the seventeenth century, Henry More and Ralph Cudworth 'transplanted to English soil the doctrine of Italian natural philosophy and were distinguished representatives of that English Platonism which had a great influence on philosophic and religious thought in England'.‡

J. T. Baker, in his excellent monograph,§ has pointed out that Isaac Newton's theory of absolute space can be traced to the influence of the Platonist Henry More, a contemporary of Newton at Cambridge. As for Newton's theory of absolute time, it is essentially that of his tutor Isaac Barrow, a mystic who expounded the Platonic concept of time.

* F. M. Cornford, *Plato and Parmenides* (1939), p. 186.

† *The Essence of Plotinus* (1934, Stephen Mackenna translation), p. 108.

‡ A. Vasiliev, *Space, Time, Motion* (1924), p. 35.

§ J. T. Baker, *An Historical and Critical Examination of English Space and Time Theories from Henry More to Bishop Berkeley* (1930).

Barrow in his *Lectiones Geometricae*, given in 1665-66, declared that time is discovered and measured through motion. He said: 'Whether things move on, or stand still; whether we sleep or wake, time flows perpetually with an even tenor.'*

We know that Newton was anxious to create in his *Principia* a theory favourable to religion. In a letter of December 10th, 1692, he confided to Richard Bentley: 'When I wrote my treatise about our system, I had an eye upon such principles as might work with considering men, for the belief of a Deity, and nothing can rejoice me more than to find it useful for that purpose.'

Hence Newton's wholesale borrowing of Platonic ideas of space and time. Coached at Cambridge by the Platonist Isaac Barrow, and influenced also by the mysticism of Jacob Boehme, Newton introduced into his *Principia* Plato's metaphysical concept of a flow of time or god-given 'duration', which 'from its own nature flows equably without relation to anything external'.†

This duration or absolute time is measured, continued Newton, 'by the means of motion, which is commonly used instead of true time; such as an hour, a day, a month or a year'.

This idea of a single universal time, unaffected by matter in motion, but measurable by means of periodic motion, prevailed in modern physics until the work of Einstein. Prior to the establishment of relativity theory, it was generally accepted in scientific circles that clock time was a measure of an independently existing 'true' or absolute time. Physicists were generally agreed, therefore, that if two events occurred at a particular instant of absolute time, those two events were absolutely simultaneous. Newton's concept of time thus involved a belief in absolute simultaneity.

The theory of relativity demolished the concept of absolute time which Newton had adopted from neo-Platonist philosophy, and excluded the false supposition that clocks measure the flow of a time which is independent of motion.

Relativity physics showed that clock measurements depend upon the relative motion of the clocks concerned. Owing to the

* Isaac Barrow, *Geometrical Lectures* (1735, London, Edmund Stone translation), p. 6.

† Newton, *Principia*, Book I, Definition 8. See also Book III, General Scholium.

constancy of the velocity of light, the numerical definition of a time interval is affected by translatory motion of the clock concerned, relative to the observer defining the time interval.

All clocks are in motion, and there is no justification for saying that a particular clock represents absolute 'true' time. Clocks in motion relative to one another will not show the same time, and no single one of them is necessarily more correct than another.

The *numerical* present thus depends upon the clock we employ to denote present time. 'Now' according to a clock on the earth is not 'now' according to a synchronous clock on, say, a star in motion relative to the earth. The numerical definition of an instant is ultimately a question of choosing a clock in a particular state of rest or motion.

Here we come to Einstein's principle of the relativity of simultaneity. This principle states that there is no such thing as absolute simultaneity – no simultaneity of events irrespective of the clocks chosen to time those events. Simultaneity is relative to the translatory motion of the clocks concerned.*

Relativity theory, having reduced problems of time to questions of choosing clocks and equating their time periods mathematically, showed time to be a quantity, but did not include a close examination of clocks themselves.

Time being a quantity, it could be treated as a dimension by the method of Minkowski, and integrated mathematically with spatial dimensions. But this mathematical achievement, great though it was, did not include a close examination or a clear definition of clocks themselves. The physicist Herbert Dingle wrote in 1939: 'There is in physics no explicit definition of a clock.'†

Content to handle temporal quantities mathematically, relativity theory did not pose the question: what does a clock measure? Nor the question: if time is a quantity, then a quantity *of what?*

To answer these questions we must turn to various clocks, ancient and modern, in order to see what they all have in common.

* The relativity of time was demonstrated experimentally by R. S. Kennedy and E. L. Thorndike, whose paper on the subject appeared in *Physical Review* (1932), vol. 42, p. 400.

† H. Dingle, *Nature* (1939), vol. 144, p. 888.

2. What is a Clock?

Lecturing at Princeton University in 1921, Einstein gave this definition of a clock: 'We understand by a clock something which provides a series of events which can be counted. . . . The series of events . . . is formed of elements all of which can be regarded as equal.'*

This definition leads directly to a materialist understanding of time, provided we realize that any physical event consists of the motion of matter.

What kind of motion gives a series of events which can be counted, and so serves as a clock? The answer, of course, is periodic motion -- motion which recurs in approximately equal amounts or cycles. These equal amounts of periodic motion can be used to measure other motion, and thus become units of time. Any system of periodic motion, showing cycles which can be counted as units, is a clock.

Certain forms of periodic motion are employed as standard clocks. The particular periodic motion which serves as our master clock is the rotatory motion of the earth on its axis. Man-made clocks are regulated to conform with the axial rotation of the earth.

The sidereal day is practically one complete axial rotation of the earth in relation to certain stars. The true solar day is one complete axial rotation of the earth in relation to the sun. The mean solar day is a numerical value based on the true solar day's variation over a 'tropical' year.

Sidereal time consists of sidereal days. Solar time consists of solar days. True solar time consists of true solar days. Mean solar time consists of mean solar days, as shown by man-made clocks in general civil use. Mean solar time has no physical existence apart from such clocks.

Man-made clocks are instruments whose periodic motion is correlated with the periodic motion of the earth. The motion of clocks used in astronomy is correlated (sychronized) with the axial rotation of the earth relative to the stars. The year (the basis of most calendars) is one complete revolution of the earth around the sun, relative to a 'fixed' star.

* Einstein, *The Meaning of Relativity* (1922), p. 2.

The calendar is a numerical correlation between the earth's axial rotation and its orbital motion around the sun. Altogether, there are ten different calendars! Our Julian calendar counts 365¼ days to one year.

The motion of manufactured clocks in general civil use is adjusted to conform with the numerical values of mean solar time. Hours and minutes are cycles of the periodic motion of manufactured clocks. If all such clocks were permanently destroyed by some disaster to our planet, hours and minutes would cease to exist. There would be no hours without man-made clocks, cycles of which *are* hours. The day is a cycle of motion which occurred repeatedly prior to the existence of the human race. But the hour, the minute and the second are human inventions.

Among primitive peoples lacking manufactured clocks, complex and highly variable periodicities are used instead of hours, minutes and seconds. M. P. Nilsson, in his *Primitive Time-Reckoning*, mentions numerous periodic events indicating the 'time of day'.

In the Society Islands, these events include 'cock-crow, the first breaking of clouds, the stirring of the flies . . . sunrise . . . sunset . . . the time at which the houses are lit up. . . .'

To describe the 'time of year', seasonal events are referred to. The Eskimos say that such and such a person was born when eggs were collected or seals caught.

To give more simple, constant and convenient periodicities, clocks were invented, and from their use the modern idea of time developed.

A clock is a physical system whose cycles of periodic motion are units of time. When we measure other motion by means of a clock, we define that motion numerically in terms of time. For example, measuring the motion of a man running a mile race, we define that motion numerically in terms of minutes and fractions of a minute.

A minute, be it noted, is a certain quantity of the motion of a clock – a quantity which serves to measure other motion in terms of time.

One of the earliest man-made clocks was the ancient Egyptian sundial, which cast a shadow that moved over lines drawn on a flat surface, as the rotation of the earth altered the direction

of the sun's rays. The passing of the shadow from one line to another was one hour. But this useful time reckoning ceased at nightfall – a serious disadvantage for the priestly astronomers who governed Egypt's economy largely by virtue of their knowledge of natural periodicities.

At night, in the absence of some other instrument for showing hours, periodic motion could be determined only by observation of the stars. The ancient Egyptians did use the changing positions of stars to determine the progress of the earth's rotation. Their primitive transit instrument for this purpose was termed *merkhet*, or 'instrument for knowing'.

The star Sirius gave ancient Egypt a valuable method of determining the periodicity of the earth's revolution around the sun. On the day that we know as July 19th, Sirius appeared on the Egyptian horizon just before sunrise, after a prolonged absence from sight. This regularly recurring event was chosen to mark the end of one year and the beginning of another. Annual observation and recording of this first heliacal rising of Sirius showed the years as a series of equal periods.

Could hours, too, be shown at night as an unbroken series of equal periods? Attempting to answer this question affirmatively, the Egyptian scientist Amenemhet invented a water clock about the year 1550 B.C. The principle of this and subsequent water clocks was the slow emptying and filling of a calibrated vessel, so constructed that succeeding levels of the water could be counted as more or less equal periods of flow. The fall or rise of water from one level to another represented an hour, after the flow had been adjusted to conform with the hour of a sundial.

The beginning and the end of this periodicity was the filling and emptying of the water-containing vessel, subdivisions of each period being the flow of water from one level to another. Introduced into Rome in the second century B.C., water clocks were used to set a limit to speeches in the Roman law courts, where 'to give speaking time' was *aquam dare* '(to give water)', and 'to waste time' was *aquam perdere* '(to lose water)'.

Water clocks, however, did not give exactly equal periods of motion, so that the hour was not a constant quantity.

Another somewhat irregular periodicity was the burning of one candle after another during the night, which was thus divided numerically into so many 'candles'.

In the fourteenth century, there appeared in Europe clocks whose periodic motion was primarily the slow repeated fall of weights, suspended by ropes from a revolving arm. The falling weight turned the single hand of the clock around the dial. Complete rotations of the hand were approximately equal periods of motion, each period being one hour.

In Nuremburg, about the year A.D. 1500, Peter Henlein employed a spring instead of a falling weight to turn the hand of his small clock. In most of these early European clocks, a novel periodic event – the striking of a bell – sounded the end of one hour and the beginning of another. Hence the origin of the word 'clock' from the French *cloche*, 'a bell'.

The difficulty with these early mechanical clocks was to find a way of making the clock hand revolve at a uniform speed, so that each hour should be the same quantity of motion as another. In the seventeenth century, Christian Huyghens solved this problem by using a pendulum (whose natural oscillation consists of approximately equal periods of motion) to regulate the motion of the clock hand.

Subsequently, in small clocks, an oscillating flywheel was employed instead of a swinging pendulum. The principle, however, continued to our own day, remained the same, namely regulation of the periodic motion of the clock hands by the natural equal periods of an oscillating body.

Recently, in some electrically driven clocks, the oscillation of a piezo-electric crystal has been used instead of a pendulum or a flywheel. A quartz crystal of this kind contracts and expands regularly if it is placed in a rapidly alternating electric field. This periodic motion of the crystal is used to regulate the periodic motion of the clock, giving the latter at least ten times more accuracy in relation to the earth's periodicity than the best pendulum clock.

What precisely is this periodicity of a mechanical clock that men laboured so long to make perfect? It is first of all the repetition of motion that has a beginning and an end, each repetition being a cycle of motion or period of time.

On the face of an ordinary household clock, the end of one period of motion (an hour) and the beginning of another is the arrival of the two hands of the clock close to two particular figures of its dial, making a certain spatial configuration. The

motion of the clock is thus divided into periods by the recurrence of dynamic spatial configurations – of certain arrangements of pointers on a dial. These periods of motion are time units, and we use them to measure other motion in terms of time.

Similarly, in the case of our cosmic clock, the end of one period of the earth's revolution around the sun and the beginning of another is a spatial configuration – a certain dynamic configuration of earth, sun and stars.

No clock is unique in showing exactly equal periods of motion. Even the axial rotations of the earth are not exactly equal periods, the length of the twenty-four hour day thus being slightly variable. As Spencer Jones has put it, 'the earth is not a perfect timekeeper'. This British astronomer continues:

'From the records of ancient observations of eclipses of the sun and moon, it has been concluded that *during the last two thousand years the day has been gradually getting longer; the average increase in the length of the day in the course of a century is about one-thousandth of a second.* In addition to this gradual but progressive increase in the length of the day, there are also irregular changes which sometimes occur with great abruptness. Thus in 1785 the rotation slowed down and in 1899 it speeded up again. During the interval from 1785 to 1899, the cumulative effect of the slowing down amounted to nearly one minute. The effect of the irregular variations in the rate of rotation may amount in the course of a year to about one second.'*

Variations in the length of the day are attributed partly to retarding frictional effects of tides on the earth's rotation, partly to changes of the earth's moment of inertia due to geological movement. 'A uniform shrinkage or expansion of the whole earth, involving a change of radius of a few inches, would be sufficient to account for the observed variations. De Sitter has pointed out that a very slight adjustment of the shape of the layers of equal density in the inside of the earth, of which the effect on the dimensions need not exceed a fraction of a millimetre, could equally well account for the observations.'†

We see here the inescapable dependence of the periods we use as time on other forms of motion. Every clock, even our cosmic clock – the rotating earth – is a form of periodic motion

* H. Spencer Jones, *Worlds Without End* (1935), p. 3.

† H. Spencer Jones, *Reports on Progress in Physics* (1938), vol. 4, p. 23.

whose cycles are increased or diminished by circumstances. Our own manufactured clocks we can compensate for disturbing influences of temperature, humidity and atmospheric pressure. But disturbances of the periods of our cosmic clock cannot be offset by compensatory devices. Time, if it can be said to march on, cannot be induced to keep completely in step with our mathematical ideal of absolutely isochronous periodicity!

3. Duration and Simultaneity

The idea of an independent universal duration is nothing but the obsolete concept of absolute time which Newton adopted from neo-Platonist circles. There is no such thing as a general duration, separate and distinct from processes of the physical world. There is only the duration of particular structures, objects, processes, events.

When we say that anything endures, or has a duration, we are merely saying that it exists, or has an existence. Quantitatively, however, the duration of anything is its existence relative to motion.

The motion which we use to define duration numerically is the periodic motion of a clock. The cycles or periods of a clock's motion are units of time.

To define the duration of a physical system, we relate the system's existence to periods of a clock's motion. The duration of a man's life in years, for instance, is the man's existence, related to so many cycles of the earth's orbital motion.

The earth in periodic motion is our master clock. A manufactured clock is synchronous with the earth when its periodic motion is numerically equivalent to the periodic motion of the earth. Thus 24 cycles of a manufactured clock's motion is equivalent to one cycle (a day) of the earth's rotatory motion.

In the absence of manufactured clocks, primitive communities define duration in terms of various periodicities, some of which are highly complex and irregular. Duration is defined by primitive peoples with reference to periodic acts of cooking, travelling, etc., or to seasonal changes, or to generations of human lives, as well as to solar or lunar appearances.

The use of clocks and the calendar enables us to determine

whether or not different physical systems co-exist with one another; whether they did so in the past; whether they will do so in the future. But there are certain limitations on such knowledge.

There is little difficulty in knowing that two atoms of oxygen co-exist in forming a single oxygen molecule, or that two streams of water turned on and off by a single tap are co-existing processes. But to know for certain whether two stars co-exist is not always impossible.

A star may have ended its existence in a final explosive disintegration. But light already emitted by it will continue to reach the earth, giving the impression that the star continues to co-exist with other stars. The *finite* character of light's velocity is responsible for this limitation of our knowledge concerning co-existence.

Another characteristic of light, namely the *constancy* of its velocity, imposes another limitation on our knowledge concerning co-existence, by making determinations of simultaneity dependent upon the state of rest or motion of the clock concerned.

Owing to the constancy of light's velocity, clock readings are affected by motion of the clocks. The time shown by a clock will thus vary according to its translatory motion as a whole, relative to different observers. An instant of time will not necessarily be given the same numerical value by different observers, owing to the constancy of the velocity of light.

Hence co-existent events which are simultaneous according to the clock of one observer will not necessarily be simultaneous according to the synchronized clock of another observer. Simultaneity, which is a numerical definition of the co-existence of events, is relative to the state of rest or motion of the clock concerned.

The principle of the relativity of simultaneity, although firmly established in modern physics, is not always clearly understood.* The principle does not state that the periodic motion of the parts of a clock is actually faster or slower according to the translatory motion of the clock as a whole. A clock does not 'go' faster with an increase in its velocity as a whole.

* See, for example, a controversy on 'the clock problem' in *Nature* (1940), vol. 145, between H. Dingle and the mathematician Campbell.

The 'distortion' of a clock's time by the clock's translatory motion is no more a physical reality than the FitzGerald-Lorentz contraction. Both this 'contraction' and the time 'distortion' are only appearances, arising from the behaviour of light in procedures of measurement. It is only *numerical definitions* of a clock's periodic motion which vary with translatory motion of the clock as a whole.

While a clock is required to measure simultaneity, a clock is not essential for determining whether different events co-exist with one another. The use of a camera, for instance, is a non-numerical method of determining co-existence.

If an appropriate photograph of the finish of a horse race shows the noses of the two horses in line with the finishing post, the arrivals of the two horses at the end of the track were two co-existent events, according to this non-numerical method of determining co-existence.

A photograph eliminates from consideration the dynamic aspect of events, and portrays only their static or structural aspect. A photograph represents events as objects, and processes as structures, by eliminating their motion from the picture. Physical reality is thus represented in a completely one-sided manner, motion being reduced to zero in a portrayal of spatial relations.

A similar one-sided representation of physical reality is made in dividing the motion of a clock into a series of instants. Each instant of time is a particular configuration of certain parts of the clock – a certain spatial relation between the hand and the dial.

In the case of our master clock, the earth is the 'hand', and the 'dial' consists of distant stars. An instant of sidereal time – the end of a sidereal year, for example – is an alignment of the earth, the sun and a distant star.

The motion of a clock is thus divided abstractly into a series of numbered instants, each instant being a spatial configuration of the clock. The continuous motion of the clock is treated as if it were a series of discontinuous instants of time.

While this abstract treatment of clock motion is a highly convenient human procedure, to say the least of it, we must not confuse it with physical time, which exists independently of human beings.

An instant is a particular position of the hand of a clock in

relation to the dial. In that position, the motion of the clock's hand is treated as if it were zero, or inappreciable. But the motion of a clock's hand is zero only when the clock has stopped! And the inappreciable time interval of the mathematician cannot be observed!

A clock whose hand is in periodic motion does not show instantaneous time, for the simple reason that the motion of the hand does not consist of discontinuous positions. Only in mathematics does the moving hand of a clock appear to consist of discontinuous positions or instants. In reality, the motion of the clock hand is continuous motion, from which instants are derived as mental abstractions.

In reality, then, there is no such thing as instantaneous simultaneity. As far as instantaneous time is concerned, simultaneity is a human abstraction, not an independently existing physical reality. The numbered instant which defines the exact time of events is merely a convenient numerical definition of their co-existence – a definition which varies with the state of rest or motion of the clock concerned.

Co-existence, on the other hand, while definable in terms of simultaneity, is a physical reality which is independent of clock time. The co-existence of different events is an independently existing physical reality, not a mental abstraction.

Numerical definitions of co-existence are made by means of clocks, but co-existence is not a human abstraction from clocks, as is simultaneity. Co-existence is existence – the existence of different events – independent of human thought.

Objects and events do not co-exist statically. On the contrary, they form, alter and terminate in the development of other objects and events. With reference to a clock, this development of things is seen as their time order.

In spite of the 'discoveries' of J. R. Dunne, past, present and future events do not co-exist in a time order, along which an individual human being passes like a general reviewing a regiment. Events show a time order precisely because they do *not* all co-exist.

Events are dynamic physical structures, some of which integrate and disintegrate before our eyes. It is this ceaseless flux of matter in motion which constitutes a time order of events, with reference to the cycles of a clock.

A time order of past events may be represented physically by an existing *spatial* order. The ordered arrangement of geological strata, for instance, is a spatial order of rocks, representing a time order of past geological events. Reconstructing those events mentally, and relating them to the cycles of a clock, we obtain a geological time-scale – a numerically defined time order of geological events.

We can even take a spatial order representing past events, and reproduce those events physically in their previous time order. An orchestral gramophone record, for instance, has a grooved surface with a certain spatial order of small indentations. Playing the record, the spatial order of its indentations produces a certain time order of musical notes, in reproducing past events of the recording orchestra's actual performance.

In addition, of course, the time order of those past events may be represented mentally. A tune may be 'running through one's head', without any gramophone to record the time order of its notes.

When we represent the time order of past events by means of numbers, we have a time-scale. The calendar is a time-scale with which we 'date' past events.

The numbers of the calendar, representing successive cycles of the earth's periodic motion, have little or no meaning except with reference to historical or other changes. One cycle of the earth's motion is very much like another. The gradual lengthening of the day does not make a significant difference between one axial rotation of the earth and the next.

A time order is practically nothing but repetition as far as a clock alone is concerned. The periodic motion of a clock is a cyclical change, in which practically the same dynamic configurations occur again and again.

The change of a clock's periodic motion is thus a 'reversible' change, in so far as the clock 'reverses' in due course to a previous configuration. Over and over again, for example, the hands of an ordinary household clock 'come back', as we say, to a particular position on the dial.

Since each cycle of a clock is practically the same as another, we cannot differentiate the first cycle of a series from the last, as far as the actual motion of the clock itself is concerned. In other words, a series of time units as such has no 'direction'.

Either end of the series can be treated as 'number one', if we confine our attention to the clock.

This means that we cannot say whether one cycle of a clock occurred before or after another, if we consider only the periodicity of the clock itself. For if we cannot tell the beginning from the end of a series of time units, one time unit can be described as either before or after another, with equal justification!

The terms *before* and *after* are thus significant only with reference to *irreversible* change. The changes of nature that are *not* repeated again and again are the ones which give a time order its 'direction'.

The flux of matter in motion gives ever different features to the physical world from hour to hour, from day to day, from year to year. We time events with reference to clocks, but the terms *before* and *after* refer to features, phases or stages of this ceaseless irreversible change.

Irreversible processes constitute what is commonly called 'the march of time'. One event is reckoned to have occurred before or after another according to its 'place' in some irreversible process.

The 'place' of an event in an irreversible process is defined numerically with reference to a particular cycle or configuration of a clock. But the direction of the time order of all the events in that process is determined by the irreversibility of the process.

An example of an irreversible change is the transmutation of radium to lead. In that transmutation, however, the electronic oscillation that produces gamma radiation is the 'reversible' change of an atomic clock.

The geological development of the earth is an irreversible change. Only probability-intoxicated mathematicians will maintain that the development of the earth's structure and life could possibly be reversed, so as to reproduce, say, the precise rock formation, flora and fauna of the Carboniferous period!

The axial rotation of the earth, however, is the 'reversible' change of a cosmic clock, the cycles of which are repeated over and over again. 'Reversible' also is the orbital motion of the earth around the sun, with reference to which we 'date' stages of the earth's geological development.

The irreversible process with which we are most familiar is

the life of a human being. How many volumes have been written on the irreversibility of this particular process? No less irreversible is the history of mankind, and the biological evolution of living things.

The irreversible change chosen by physicists, in determining the 'direction' of the time order of events, is change of entropy.

Entropy is the amount of a system's energy which is not available for the performance of mechanical work. A system's entropy tends to increase. The second law of thermodynamics expresses this tendency in stating that, within a closed system, entropy always increases; in other words, energy becomes less and less available for mechanical work.

At any given instant, the degree to which a physical system's total energy has become unavailable for mechanical work marks a particular phase of the system's irreversible change.

To give a physical significance to the terms *before* and *after*, physicists refer a system's successive events to the entropy of the system at the respective times of those events. Of two events A and B, B is said to have occurred after A, if entropy at the time of B was greater than entropy at the time of A.

Entropy has therefore been termed 'time's arrow', since successive instants of time can be correlated with ever increasing values of a closed system's entropy. Considered as a criterion of the irreversibility of physical change, entropy is thus an indication of the 'direction' of a time order.

The late Professor Eddington liked to imagine that entropy was the only criterion for determining the 'direction' of a time order. Any geologist, however, knows better. No one acquainted with the facts of geology will ponder whether days of the Eocene Period occurred before or after days of the Pleistocene. The record of the rocks is a perfectly valid indication of the 'direction' of the geological time-scale, without any reference to entropy.

Cosmology too demands no consideration of entropy, in order to determine whether one period of time was before or after another.

When we come to the present development of human society, all talk of entropy as 'time's arrow' becomes meaningless. The recorded history of mankind – the time order of which is defined numerically by the calendar – gives us the 'direction' of that order.

Incidentally, the validity of the second law of thermodynamics is limited by the fact that there is no such thing as a closed physical system, i.e. a system which neither gains nor loses energy. In the long run, at any rate, a physical system gains or loses energy, and the second law of thermodynamics thus ceases to be strictly applicable to it.

4. Biological Time

Suppose a normal man is enclosed in a completely dark and soundless room for half a day. On being released, he is able to state approximately how many hours he was imprisoned, even though he was cut off from all perception of external physical time. What internal clock allows him to estimate a period of solar time under such conditions.

This question is beyond the present scope of physics, but it is one which physiologists are beginning to answer from a knowledge of bodily rhythms.

'Inward time', to use Carrel's phrase, consists of periodic bodily processes which form the physiological basis of our sense of time. Experience of environmental clocks, particularly the periodic motion of the earth, is gradually related mentally to these rhythmical bodily processes which constitute 'inward time'. In other words, a human being possesses physiological clocks whose time he learns to correlate mentally with the physical clocks of his environment. The organ which establishes a mental correlation between internal physiological periodicities and clocks of the external physical world is the brain.

Pavlov and his colleagues have demonstrated how the brain of a dog can establish a physiological correlation between an external environmental periodicity and a bodily rhythm. One experiment was the periodic production of salivation, by a conditioned stimulus occurring every thirty minutes. After cessation of the stimulus, salivation continued to occur for a time every thirty minutes, as a conditioned reflex of the dog's cerebral cortex. The animal's internal physiological clocks 'timed' this continued periodic salivation, through a previous correlation with the periodicity of the external stimulus.

The internal physiological clocks which help us to estimate

external physical time have been indicated by Pavlov as follows:

'Many cyclic phenomena take place inside the animal's body. In the course of twenty-four hours the brain receives a very considerable number of stimuli, becomes fatigued, and again restored through sleep. The alimentary canal is periodically filled or emptied; and, in fact, changes in practically all the component tissues, and parts of the organism are capable of influencing the cerebral hemispheres. This continuous cycle of direct and indirect influences upon the nervous activity constitutes the physiological basis for the estimation of duration of time.'*

Everyone is familiar with such bodily rhythms as the heartbeat and the arterial pulse, which Galileo is said to have used as a clock in timing the swing of a hanging lamp in Pisa cathedral. The respiratory cycle of inspiration and expiration, and the sexual periodicity which includes menstruation, are other rhythms equally well known. Less familiar, perhaps, are the cyclical processes of individual cells of the body.

Every muscle fibre of the heart, for instance, contracts and relaxes rhythmically by reason of its dynamic molecular structure, the composition of its surrounding field, and the centrifugal nerve-impulses which regulate its periodic contractions.

Nerve cells possess this power of acting periodically, their cycle consisting of the discharge of an impulse along a nerve fibre, followed by a refractory period of a fraction of a second, in which no further discharge of nerve impulses can occur. This rhythmical activity of nerve cells, in the medullary part of the central nervous system, caused periodic contractions of fibres of the diaphragm and chest wall muscles, giving the respiratory cycle of inspiration and expiration.

In the brain itself, a ten-per-second rise and fall of electric potential of the cerebral cortex constitutes the well-known alpha rhythm, which is recorded by means of the electroencephalograph. First demonstrated by Hans Berger, the alpha rhythm is a simultaneous cyclical change of voltage on the part of many millions of nerve cells, all beating together electrically as one cerebral clock.

The rise and fall of electric potential of each nerve cell is an expression of cyclical physico-chemical processes occurring with-

* I. P. Pavlov, *Conditioned Reflexes* (1927), p. 43.

in the cell. What these processes are has been partially revealed by Warburg, Wieland, Keilin, Szent-Györgyi and other bio-chemists. The periodic energy changes of the cell, of which the alpha rhythm is an expression, are based upon oxidation-reduction processes of cell respiration.

The respiration of a living cell is essentially an oxidation of hydrogen, which forms water and releases energy. This oxidation takes place in a series of chemical reactions which continue to be repeated as long as the cell respires.

In the cycle of respiration within a cell, hydrogen atoms are extracted from its foodstuffs, while oxygen atoms join up with a series of catalytic iron compounds – the cytochromes. From the hydrogen atoms, electrons are passed by these metallic catalysts to the oxygen atoms, which are thereby 'activated' and made ready for their energy-releasing union with hydrogen.

Each union of oxygen and hydrogen atom calls for a fresh circulation of electrons through a series of oxidation-reduction exchanges, so that a further energy-releasing and water-forming union of oxygen and hydrogen may take place. The whole process of cell respiration is thus a cyclical one, in which certain physico-chemical processes are repeated over and over again.

Theoretically, the physiological time of a cell might be reckoned in terms of the cell's respiratory cycles, just as physical time can be reckoned in terms of the earth's seasonal cycles.

There are close though little explored connections between the physical cycles of the earth and various physiological cycles of the human body. The human organism 'swings in a definite rhythm of increasing and decreasing pH, of increasing and decreasing metabolism, of increasing and decreasing blood pressure, all closely related to the metereological environment'.*

Illustrating the phasic relationship between physical and physiological periodicities, W. F. Petersen calls a living human being a 'cosmic resonator'.

Chemically, we see certain cyclical connections between a human being and the surrounding environment. Carbon, oxygen, hydrogen, nitrogen, sulphur, calcium, phosphorus and other atoms are continually entering the body as nutriment, and leaving the body after periods of stay within the tissues.

* W. F. Petersen, *The Patient and the Weather* (1936), vol. 1, p. vii.

The use of isotopes as 'tagged' atoms permits us to trace and record this atomic circulation of chemical elements in and out of the body. The average stay of an atom of phosphorus within the human body is thus found to be about one month.

Very roughly, a man's age could be defined numerically in terms of physico-chemical cycles instead of planetary cycles. For the physico-chemical rhythms of the human body are natural clocks, no less than the physical rhythms of the solar system.

All physiological rhythms, however, being subject to much variation, are unsuitable as standards of periodic motion. Physiological clocks are too irregular in their motion to provide standard time, although they can usually give approximate mental estimates of standard physical time.

The dependence of mental estimations of physical time on brain activity is shown by effects of heat and of drugs on the brain. M. Francois found that on raising the temperature of an individual's brain by means of a high-frequency electric current, the individual's estimation of external physical time was altered.* When the temperature of the body (including the brain) was raised by a half to one degree Centigrade, mental estimations of one second became less.

Significant in this connection is the fact that a rise of body temperature facilitates release of oxygen from the oxyhaemoglobin of the blood.

Drugs which act on the brain, and thereby affect mental estimations on physical time, include hashish and opium. De Quincy has given us the following classical description of his sense of time under the influence of opium:

'Space swelled, and was amplified to an extent of unutterable infinity. This, however, did not disturb me so much as the vast expansion of time; I sometimes seemed to have lived for seventy to a hundred years in one night; nay, sometimes had feelings representative of a millennium passed in that time, or, however, of a duration far beyond the limit of human experience.'†

Such disturbances of the sense of time arise from some interference by the drug with oxidative processes of brain metabolism. J. H. Quastel and other biochemists have emphasized that

* M. Francois, *Comptes rendus soc. biol.* (1928), vol. 98, p. 152. See also H. Hoagland, *Pacemakers in Relation to Aspects of Behaviour* (1935).

† De Quincy, *Confessions of an Opium Eater* (1927 edition), pp. 114, 115.

narcotics 'inhibit specifically, at low concentrations, the oxidations by brain of substances essential in the metabolism of carbohydrate, such as glucose, lactic acid and pyruvic acid'.*

Since carbohydrate is almost the sole fuel of the brain, the physiological activity of which produces psychological phenomena, it is not surprising that interference with cerebral carbohydrate metabolism affects the mind, and distorts mental estimations of external physical time.

Obscure physico-chemical disturbances of the brain underlie mental disorder, cases of which show various distortions of the sense of time. Patients with mental disorder are frequently found to have grossly erroneous ideas of time†, which seems to 'go' very quickly or very slowly, or 'the wrong way'. Further investigations of these abnormalities will undoubtedly shed much light on how we form our normal estimations of external physical time.

5. Past, Present, Future

Since the publication of H. G. Wells' *Time Machine*, the idea of travelling through time has had a peculiar fascination. Supported by a yearning to escape from the present, the idea of travelling into the past or the future has more than a passing attraction. And since time has come to be regarded as a dimension, the possibility of time travel has become a subject of much discussion.

Theoretically, science shows that it is possible to 'travel' into the future. A human being, if immobilized in a state of suspended animation by suitable freezing, could quite conceivably be thawed into renewed life a hundred years hence.

Among the forms of life which have actually survived freezing are vinegar eels, cancer cells and the spirochaete which causes syphilis‡. Chick embryos have renewed their develop-

* Irvine Page, *The Chemistry of the Brain* (1937), p. 284.

† See R. L. Worrall, The Basis of Insanity, *British Journal of Medical Psychology* (1941), vol. 19, p. 95; also Aubrey Lewis, The Experience of Time in Mental Disorder, *Proceedings of the Royal Society of Medicine* (1932), vol. 25, p. 611.

‡ See G. B. Mider and J. J. Morton, *American Journal of Cancer* (1939), vol. 25, p. 502; also R. B. Haines, *Proceedings of the Royal Society*, Series B (1938), vol. 124, p. 451.

ment after a ten-day suspension of animation at –5°C.*

In 1947, Soviet scientists were reported to have taken bacilli from Arctic earth where they had been frozen for thousands of years, and to have thawed them into renewed life.

Suspended animation is essentially the elimination of those physico-chemical processes which involve the ageing of a living organism. By freezing, we reduce the motion of its atoms and molecules to vibrations about mean positions. We thus immobilize the organism's constituent particles, in so far as we present the migratory molecular movements of chemical change. Ageing is thereby arrested, *in an environment whose changes continue unabated.*

In the production of suspended animation by freezing lies a cardinal principle of 'travel'. It is this: things 'travel' into the future in so far as they remain unchanged in the midst of change. To maintain a constant structure is to be 'carried' into the future by the changes of other structures.

The 'passage of time' is essentially the integration and disintegration of physical systems, living and non-living. Anything that remains integrated, in the midst of the destruction and formation of other systems, is making a 'journey through time'.

A structure 'travels forward through time' in remaining integrated. Take, for example, a fossel trilobite – the mineralized body of a small sea creature that lived nearly five hundred million years ago.

When we define the duration of this fossil crustacean in terms of years, we are relating its existence to periodic motion – the periodic motion of the earth around the sun. We thus obtain a numerical definition of the fossil's duration, relative to periodic motion.

If, however, we wish to survey the fossil's 'passage through time', we must consider its duration relative to the various forms of motion which constitute irreversible change. Existing unchanged in the midst of the innumerable integrative and disintegrative processes of irreversible change, the trilobite fossil succeeded in 'travelling through time'.

In this 'time journey', our fossil co-existed with the development of vertebrate organisms and the deposition of sedimentary rocks in the Silurian Period; the swarming of fish in the warm

* N. Lake, *Lancet* (1917), vol. 2, p. 557.

Devonian seas; the growth of the large trees and giant ferns of the Carboniferous Period; the rise of cold-blooded egg-laying lizards in the Triassic; the evolution of the giant dinosaurs and primitive birds in the Jurassic; the sinking of countless Foraminifera in the waters of the Cretaceous Period; the continental drifts, mountain-building and mammalian life of the Tertiary Era; the appearance of ape-men in the Pliocene; the advances and retreats of Polar ice, the loess deposition, and the volcanic eruptions of the Pleistocene Period, when the brain of man reached its present stage of development.

The human brain, the most complex and unique product of evolution, is a means of reconstructing the past in thought. The human brain creates mental pictures of objects and events which have ceased to exist, and thus belong to the absolute past.

We have to distinguish the absolute past from the relative past. The absolute past is that which has ceased to exist. The relative past, on the other hand, is a purely numerical relationship between events.

An event is reckoned to belong to the relative past solely on a basis of human measurements, made by means of a clock and light rays. Other measurements – equally accurate, but made with a second clock in motion relative to the first one – could 'place' the same event in the relative future.

All of which simply amounts to the principle of the relativity of simultaneity. An event belongs to the relative past or the relative future, according to the state of rest or motion of the clock employed to denote its time.

Clocks are also used to number events of the absolute past. In human thought, things which have ceased to exist are related to past cycles of a clock's periodic motion. We thus obtain a time-scale of the absolute past.

Each unit of a natural time-scale is a numbered cycle of a clock's periodic motion. The co-existence of past events or processes can be defined numerically with reference to a particular unit of the time-scale.

For example, the year A.D. 1789 is a unit of our historical time-scale; it denotes numerically the co-existence of two outstanding social events – the outbreak of the French Revolution, and the constitutional establishment of the United States of America.

Past events which did not co-exist are represented by different numbers of a time-scale, and the different consecutive numbers of the time-scale indicate whether one event occurred before or after another.

The geological time-scale is a natural time-scale. The first numbered units of the scale represent the beginnings of the earth. The end of the scale represents existing geological structures. The time-scale as a whole is the age of the earth in terms of years – about 3,500 million years, according to a modern estimate.

A very different time-scale is the arbitrary mathematical construction of E. A. Milne – an arbitrary time-scale designed to define numerically the 'age' of the universe. Milne has rejected relativity theory in elaborating the old idea of one universal time (cosmic time), separate and distinct from motion.

Embracing a theological doctrine of creation, Milne has postulated an origin of cosmic time in a creation of the universe.* The whole period of time from the alleged creation of the universe to the present day is Milne's 'kinematical' time-scale, which is arbitrarily divided into an infinite number of unequal time units.

The units of this arbitrary time-scale are periods which become longer and longer as time goes on. Going back in Milne time, the nearer one gets to 'creation', the shorter are the units of time. According to this concept of time, the universe is expanding and so are all atoms.

Burdened by what J. B. S. Haldane euphemistically terms the 'oddities' of his original theory, Milne has constructed a 'dynamical' time-scale, with no beginning of time. This dynamical scale is a period of time of infinite duration, divided up into equal and purely arbitrary time units.

'If we adopt the dynamical time-scale', writes J. B. S. Haldane, 'we find that atoms are not expanding, nor is the universe. The length of the day and year remains constant save for the effects of friction. The spiral nebulae are not flying apart. And there was no creation at any time in the past. Time stretches backwards and forwards for ever.'†

Haldane, who appears to be fascinated by Milne's mental gymnastics in skipping from one time-scale to another, continues:

* E. A. Milne, *Relativity, Gravitation and World Structure* (1935), pp. 138-140.

† J. B. S. Haldane, *The Marxist Philosophy and the Sciences* (1938), pp. 66, 67.

'It is important to note that it makes no difference at all to our predictions of observable phenomena which of these two schemes we adopt. Such indifference is often attacked by materialists as a concession to positivism. I believe that this attack is unjustified. . . . The Order of Events in time within a given material system is an objective fact. The scale on which they are to be measured is a matter of convenience.'

Haldane here ignores the fact that Milne's kinematical time-scale involves a theological assumption, namely a beginning of time at a supposed creation of the universe.

Milne's whole theory is a reactionary reversion to Newton's concept of absolute time, existing independently of matter in motion. According to Milne, everything exists *in* a single universal time, the origin of which was the creation of the universe.

Milne's dynamical time-scale does not exclude the essentially theological idea of creation. On the contrary, the dynamical time-scale is merely a logarithmic equivalent of the kinematical time-scale, the beginning of which marks the creation of the universe.

Milne has emphasized that his dynamical scale is merely 'a human, ephemeral method of time-measurement which has arisen owing to the fundamental laws of dynamics having been discovered empirically'.* It is the kinematical time-scale, with its emphasis on creation, which characterizes Milne's *a priori* assumptions.

How far Milne is from a scientific approach to problems of cosmology may be judged from the following passages in his book, ***Relativity, Gravitation and World Structure*** :

'If I am asked for a description of the universe independent of any observer, I reply that the question is impious. Even to conceive of such a question is to imagine as possible to man the assumption of the attributes of deity . . .'

'The system, created, goes on itself without further acts of creation. . . . But creation demands a first Cause. . . . One can say if one pleases that we have found God in the universe. . . . '†

As regards the concept of an expanding universe, Milne's dynamical time-scale is not necessary for a rejection of this idea.

* E. A. Milne, Kinematics, Dynamics and the Scale of Time, ***Proceedings of the Royal Society***, Series A, 1937, vol. 158, p. 324.

† E. A. Milne, ***Relativity, Gravitation and World Structure*** (1935), p. 139.

From different standpoints, Zwicky, Schrödinger* and Schneiderov† have maintained that the red shift of spectral lines in light from the spiral nebulae does not indicate an expanding universe.

Another theory of time which hinges on hypothetical 'observers' is that of J. W. Dunne, who likewise arrives at an 'ultimate irrationality' – 'the ultimate observer who makes the picture'.‡

Milne's observer is an invisible being astride a dimensionless particle. Dunne's observer is a mind which is repeated serially in an 'infinite regress'.

Dunne follows Aristotle in adopting the idea of an infinite regress for 'explaining' the physical world. Aristotle imagined that every physical movement was necessarily initiated by a prior 'mover', which was itself set in motion by another preceding mover, and so on *ad infinitum* back towards an ultimate 'Prime Mover'.

Dunne imagines the time of an individual 'observer' must be embraced by the time of another observer; this in turn must be embraced by the time of still another observer, and so on in an infinite time regress towards an 'ultimate observer'.

Each of Dunne's 'observers' is an individual mind, which is repeated in an endless series of minds! This, we are told, gives the individual a species of immortality! Dunne's 'ultimate observer', like Aristotle's 'prime mover', is a ghostly entity whose irrationality is the hallmark of divinity.

In his *Serial Universe*, Dunne reveals the philosophical idealism which underlies his 'new immortality'. He writes: 'The real time regress in the world of physics is the regress of the psychophysical observer who lies behind all nervous matter – a physical creature indeed, but one confined to the realms of biology.'

Evidently, Dunne is telling us that time does not exist apart from the mind of man. Previously (p. 72), he writes that 'time is an analytical device'; also (p. 26): 'We may use the time regress because it gives us a valid account of the universe in relation to ourselves.'

The universe, however, exists independently of ourselves, and physicists endeavour to represent the universe without

* E. Schrödinger, *Nature*, September 30, 1939.

† A. J. Schneiderov, *Nature*, March 17, 1945.

‡ J. W. Dunne, *The Serial Universe* (1934), p. 237.

reference to particular observers. The time of physics is the time of clocks which tick independently of human beings. Dunne's egocentric concept of time has little or no relation to physical time, which is the general quantitative aspect of motion.

Dunne betrays the philosophical idealism which underlies his serialism when he writes: 'The only thing which is real, in the sense of non-subjective . . . is the "time I" stretch of brain plus sensory phenomena.'* This is merely a roundabout way of saying that the objective physical reality does not exist apart from an individual human being – who is the "first term" of an infinite psychological regress of individuals.

More outright expressions of philosophical idealism with regard to time commence historically with St. Augustine, for whom time was 'only a subjective mode under which motion is conceived'.†

Essentially the same opinion was revived by Kant, who held that space and time are forms of thought. Time, wrote Kant, 'is nothing but the form of the internal sense, that is, of our intuition of ourselves, and of our internal state . . . simply a subjective condition. . . .'‡

With variations, this opinion that time is purely subjective crops up in the writings of numerous authors, who appear to be under the impression that what they are saying is new. Philosophers as far apart as Leibnitz and Bergson join hands in concluding that time is subjective. The philosopher of Italian Fascism, Giovanno Gentile, likewise made out time to be 'a form of mind'.

This idealist view of time has found its adherents among physicists. Ernst Mach asserted that 'space and time are well-ordered sets of sensations'.§ Hermann Weyl declared time to be 'the primitive form of the stream of consciousness'.|| James Jeans wrote that time is 'a fiction created by our own minds'.¶

According to these philosophical idealists, the universe was timeless until man arrived on the scene. Yet long before man existed, clocks were keeping time as they are today. Before the ape-like ancestors of modern man began to walk the earth, the

* J. W. Dunne, *Nothing Dies* (1940), pp. 82, 83.
† C. R. S. Harris, *Duns Scotus* (1927), vol. 2, p. 130.
‡ Kant, *Critique of Pure Reason* (English ed., 1881), pp 29, 31
§ E. Mach, *The Science of Mechanics* (1902), p. 506.
|| H. Weyl, *Space, Time, Matter* (1922), p. 5.
¶ J. Jeans, *The New Background of Science* (1934), p. 99.

planet itself was sweeping out the days and years of its periodic motion.

Mathematical representations of time are, of course, products of the human mind. The space-time continuum of relativity theory is a mental abstraction from a physical reality, namely the gravitational field. And *numerical definitions* of time are made by human beings. The numbers of the calendar, for instance, are based in the first place upon human denotation of a particular year as the year one, A.D.

Objectively, however, physical time exists independently of human thought. For physical time is the quantitative aspect of motion. It is the motion of matter which we measure with clocks and call *time.*

In general, physical time is the quantitative aspect of motion, including all its various forms: the translatory motion of macroscopic bodies, the rotatory motion of atoms, the spin of subatomic particles, the electromagnetic motion of light, the periodic motion of clocks, and so on.

Measured by means of the periodic motion of a clock, any quantity of motion, of any kind, can be defined numerically in terms of time.

Contrary to the belief of more than one mathematician, our fundamental derivation is time from motion, not motion from time. Before we can treat translatory motion as a mathematical function of time with distance, *we have to take quantities of a clock's motion as units of time.*

Time data concerning actual physical processes does not come from the formulae of mathematicians. Anyone who attempts to time a race with a mathematical function is doomed to disappointment! To time a race or any other physical phenomenon, the motion of a clock is required.

In actual practice, numerical time data concerning physical reality is derived from the motion of clocks. The abstract time quantities of mathematics are derived ultimately from the concrete cycles of periodic motion.

Contrary to the belief of more than one philosopher, *physical* time has no natural divisions separating the past from the present, or the present from the future. Physical time presents no instantaneous present for a convenient separation of the past from the future. Only in human thought are there definite

divisions between past, present and future. Objectively, 'past, present and future' are 'telescoped' into one another as one single physical reality, namely matter in motion. As far as physical reality is concerned, 'the past' consists of material structures, 'the future' of the various forms of motion that modify those structures destroy them, and create new structures. The 'passage of time' is the disintegration and integration of material structures, through various forms of the motion of matter.

Chapter VII

ENERGY

What is energy? On this crucial question, physicists preserve a discreet silence. The question is usually marked 'metaphysical' and pigeon-holed without comment. Materialists, on the other hand, endeavour to attain the utmost clarity and consistency concerning the fundamental character of energy.

Some fifty years ago, the physicist Henri Poincaré did attempt to find a comprehensive definition of energy. He summed up his failure in these words: 'It is impossible to find a general definition . . . nothing is left but an enunciation: – there is something which remains constant.'*

The reason for this failure to define energy in general terms is to be found in the historical development of theoretical physics, and in the current assumption that matter is absolutely inert.

The present concept of energy developed out of the idea that matter is absolutely inert, and is moved by non-material 'forces'.

Newton insisted that inertia is the sole fundamental characteristic of matter, and he defined inertia as matter's 'power of resisting' mechanical change. The weight of his authority did much to establish in modern science the idea that matter is absolutely inert. But this idea had a far more ancient origin, in the *Physics* of Aristotle.

Aristotle asserted that motion originates not in matter itself, but ultimately in some non-material agency – some god-like 'Prime Mover'. Aristotle strongly opposed the view that matter is self-motivated, and he thus laid down the foundation of Newton's concept of purely inert matter.

Newton demolished Aristotle's opinion that a body will come to rest unless maintained in motion by something external to it. But Newton repeated Aristotle's assertion that matter is absolutely insert.

According to Newton's law of inertia, any change of a body's

* Henri Poincaré, *Science and Hypothesis* (1905), p. 127.

state of rest or uniform motion is necessarily due to some external agency. That agency may be contact with another body. Otherwise, maintained Newton, change of a body's state of rest or motion is due to some non-material 'force' or 'spirit'.

In the year 1686, in the *Acta Eruditorum*, Leibnitz contended that a moving body has a force – *vis viva* – equal to the product of its mass and the square of its velocity. Early in the nineteenth century, G. G. Coriolis amended this formulation. This 'moving force' of a body, said Coriolis, is *half* the product of the body's mass and the square of its velocity.

In 1807, the physician Thomas Young applied the term *energy* to this 'moving force' (*vis viva*) of a material body. Half a century elapsed before the term energy was accepted by Young's colleagues, who seldom took the trouble to read the writings of this pioneer in more than one science.

Since matter was assumed to be absolutely inert, 'moving force' was regarded as something separate and distinct from material bodies, though associated with them. Therefore, when the term *energy* replaced the term *moving force*, a body's energy of motion was likewise regarded as something separate and distinct from that body, though associated with it.

Energy, like force, was thus considered to be a non-material entity, responsible in the last analysis for all changes in the state of rest or motion of material bodies. 'The term "energy",' wrote the scientist J. B. Stallo in the second half of the nineteenth century, 'denotes the cause of motion.'

In 1826, G. G. Coriolis had suggested the term *work* for the mechanical effect of a force. 'Work', said Coriolis, 'might be defined as the product of a force and the distance through which it acts.'* Adopting this suggestion, the engineer Poncelet defined a unit of work as the force expended in raising a mass of one kilogramme to a height of one metre. In this case, the work done by the force was against gravity.

The effect of a force acting against inertia was formulated as the product of a body's mass and the acceleration imparted to it by the force.

When the term *energy* replaced the term *force*, an expenditure or transference of a certain amount of energy was seen to result

* See J. T. Merz, *A History of European Thought in the Nineteenth Century* (1896), vol. 2, pp. 100, 101.

in the performance of a certain amount of work. Energy thus became defined as 'capacity to do work'. Work, on the other hand, was defined by Clerk Maxwell and others as 'transference of energy'.

Prior to the middle of the nineteenth century, this relationship between work on the one hand, and energy or 'moving force' on the other, was formulated only for mechanical phenomena.

It was easy to observe the effect of force or energy expended in overcoming gravity, or in producing acceleration. But what of energy expended without any apparent mechanical effect? What of the force used in generating heat? What became of the energy transferred in raising the temperature of a body?

An old philosophical tradition led to the solution of this problem. Expressed by Huyghens in the *Journal des Savants* of March, 1699, this belief was that forces cannot be destroyed. Somehow or other, it was thought, force must be conserved. And in so far as a force was considered to be a cause, its conservation was evidently to be found in some equal effect.

This idea led Leibnitz to anticipate the principle of the conservation of energy. In his fifth letter to Clerk, Leibnitz declared that when two bodies collide, no force is lost. Some of the force, wrote Leibnitz, is then transferred to motion of the constituent particles of those bodies, 'they being agitated inwardly by the force of the collision . . . the forces are not destroyed but dissipated among the minute parts'.

The idea that force or energy must be conserved eventually led to experiments proving the principle of the conservation of energy. The most important of these experiments showed the mechanical equivalent of heat.

In 1798, Rumford published his celebrated Munich experiments, indicating that heat was a 'force' of motion. Little notice was taken of this publication, which cut across the prevailing opinion that heat was a substance, namely 'caloric'.

In spite of the orthodox hypostasy that heat was an entity, a few individuals followed up the rejected idea that heat is the force of particles in motion. And thereby these pioneers arrived at the conclusion that mechanical force and heat are convertible one into the other.

The idea that force is conserved, and can exist in various forms, was in the air, so to speak, from the beginning of the

nineteenth century. The earliest complete statement that mechanical force is transformable into an equivalent amount of heat is apparently contained in some notes written by Sadi Carnot about 1830 and published by his brother in a biography of 1878.

Carnot planned experiments to test his estimate of the mechanical equivalent of heat. But in 1836, he died with his notes unpublished.

M. Seguin, in his *De L'influence des chemins de fer* (1839), published a rough estimate of the mechanical equivalent of heat, but without a significant exposition of the principle involved.

F. Mohr, in an obscure Vienna Journal, published in 1837 a short memoir (On the Nature of Heat), in which he suggested that force (*Kraft*), is conserved throughout the whole range of mechanical, thermal and other changes.

The first substantiated statement of this principle – the principle of the conservation of energy – was made by Robert Mayer, a young German physician whose chain of reasoning started from a physiological observation.

Mayer based his theory that energy is conserved on the work of Leibnitz on mechanical force, of Lavoisier on heat of combustion, and of Dulong on the heat produced by compression of a gas. Mayer's reasoning was also based on the idea that forces are causes, and that cause and effect are equal.

Mayer's great contribution to science was first published in Liebig's *Annalen*, after having been rejected by the leading journal of the day (Poggendorf's periodical). The reception accorded to him by the world of science drove Mayer to attempted suicide. Only after his death did his epoch-making work become recognized, especially through the efforts of John Tyndall.

'A force once in existence cannot be annihilated, it can only change its form.'* Proceeding logically from this premiss, Mayer calculated the amount of heat corresponding to a given quantity of mechanical force. In this calculation, he considered heat as a form of indestructible force; that is to say, as a form of energy.

* J. R. Mayer, On the Forces of Inorganic Nature (1842), translated in the *Philosophical Magazine* (1862), vol. 24, p. 371.

Mayer treated mechanical force as another form of energy – mechanical energy.

As a measure of mechanical energy, Mayer took the force of a body falling freely to earth from a certain height. Asking how much heat corresponds to that amount of mechanical energy, Mayer replied from his own calculations: 'The warming of a given weight of water from 0°C. to 1°C. corresponds to the fall of an equal weight from the height of about 365 metres.'

Publishing this estimated mechanical equivalent of heat in the year 1862, the editor of the *Philosophical Magazine* added the following note to Mayer's paper: 'When the corrected specific heat of air is introduced into the calculation, this number is increased and agrees with the experimental determinations of Mr. Joule.'

Mayer checked his calculated estimate of the mechanical equivalent of heat in a paper factory, by measuring the rising temperature of the pulp, which was being stirred with the expenditure of five horse-power. 'The resulting amount of heat was found, when the losses were taken into account, to agree with his equivalent.'*

In the year following the appearance of Mayer's first paper (1842), the more accurate experiments of J. P. Joule were published.† Joule, like Mayer, proceeded from the assumption that physical forces are indestructible, and convertible one into the other. His experiments confirmed the theory which Mayer was the first to formulate.

This theory, which became known later as the principle of the conservation of energy, stated that physical forces are convertible one into the other, but remain conserved in amount throughout such transformations. The founder and other pioneers of the theory expounded it in a symposium, *The Correlation and Conservation of Forces* (1865), edited by E. L. Youmans.

Subsequently, with the general adoption of the term *energy*, 'correlated forces' became known as forms of energy, and the principle of the conservation of energy expressed what was previously known as 'the conservation of forces'.

Joule's crucial experiments, on the mutual convertibility of

* P. Lenard, *Great Men of Science* (1933), p. 279.

† In the same year (1843), L. A. Colding presented to the Royal Society of Copenhagen his own evidence for the principle of the conservation of energy.

mechanical 'force' and heat, made little impression for some years on his colleagues. 'It was in the year 1843', wrote Joule, 'that I read a paper "On the Calorific Effects of Magneto-Electricity and the Mechanical Equivalent of Heat" to the Chemical Section of the British Association at Cork. With the exception of some eminent men . . . the subject did not excite much general attention, so that when I brought it forward again at the meeting in 1847, the chairman suggested that, as the business of the Section pressed, I should not read any paper, but confine myself to a short verbal description of my experiments. This I endeavoured to do, and discussion not being invited, the communication would have passed without comment if a young man had not risen in the Section, and by his intelligent observations created a lively interest in the new theory. The young man was William Thomson.'

Adopting Young's term *energy* for transformable indestructible 'forces', William Thomson (Lord Kelvin), together with W. J. M. Rankine, helped to establish the principle of the conservation of energy – the first law of thermodynamics. They introduced the concept of potential energy ('energy of position'), in contrast to kinetic energy ('energy of motion').

Kelvin and Clausius formulated the second law of thermodynamics. This second law states that in a closed system, the proportion of energy which is unavailable for mechanical work tends to increase. That is to say, the entropy of a closed system tends to increase.

Today, physicists who fail to grasp the historical development of their own science are unaware that the concept of energy is essentially that of 'convertible indestructible force'. From Leibnitz to Mayer and Joule, the idea of non-material indestructible force, capable of assuming many different forms while remaining constant in amount, developed into the principle of the conservation of energy.

Through the work of Mayer, Joule, Colding, Oersted, Faraday and others, the concept that correlated mechanical, thermal, electric and magnetic forces are conserved became the principle of the conservation of energy – the basic principle of modern science. But energy itself, which is actually a quantity, came to be regarded as an entity – a non-material 'something' which remains constant in amount.

This false view that energy is a non-material entity originated historically in a philosophical idea – the old idea that non-material forces are responsible for changes in the motion of allegedly inert matter.

The generally accepted idea that matter is absolutely inert involved the view that physical changes are due to non-material forces. In the second half of the nineteenth century, 'forces' were measured, correlated, quantitatively, and regarded as forms of 'non-material' energy.

The Aristotelian idea that matter is absolutely inert thus led – through the complementary concept of 'force' – to an artificial splitting of physical reality into matter and 'non-material' energy.

Measured in terms of mass, matter was apparently conserved. Measured in terms of work, energy remained conserved. And only that which remained conserved was admitted to be a physical reality.

Thus the physicist P. G. Tait could write in 1895: 'The only other known thing in the physical universe which is conserved in the same sense as matter is conserved is energy. Hence we naturally consider energy as the other objective reality in the physical universe. . .'*

Energy was thus elevated to the status of a 'thing'. Hypostasizing energy from a quantity into an entity, P. G. Tait and Balfour Stewart declared: 'The only real things in the world are matter and energy, and of these matter is simply passive.'† Oliver Heaviside was more succinct. 'There are only two things in the world', he said, 'matter and energy: everything else is moonshine.'

This artificial slicing of physical reality into matter and energy was based upon the idea that matter and energy were conserved independently as two entities, absolutely separate and distinct from one another. As late as about 1920, a great modern physicist could write: 'Only what is conserved has the right to be considered a physical existence, whether it is tangible and ponderable like matter, or intangible and imponderable like energy.'‡

* P. G. Tait, *Dynamics* (1895).

† P. G. Tait and Balfour Stewart, *The Unseen Universe* (1875).

‡ F. Soddy, *Matter and Energy*, p. 108.

In this artificial division of physical reality into matter and energy, matter was held to consist essentially of mass, belonging solely to absolutely discrete particles. Matter, consisting of particles with mass, was thus the 'ponderable' constituent of physical reality. Energy, on the other hand, was 'imponderable', being allegedly devoid of mass.

The idea that energy was an 'imponderable', distinguished from matter by lack of mass, prevailed in physics until Einstein demolished it with his formula:

$$\mathrm{E} = mc^2$$

where E is the total energy of a body, m the mass of the body, and c the velocity of light *in vacuo.*

This formula expresses Einstein's proof that energy and mass are equivalent quantities. With this proof, we see that energy and mass are not absolutely separate and distinct from one another. An increase of a body's velocity, involving an increase of its energy, means that the mass of the body increases in accordance with Einstein's formula. Equally so, an increase of a body's mass means an increase of its total energy.

With this proof that the mass of a body changes with change of velocity, the principle of the conservation of mass was discarded. The principle of the conservation of energy, however, was maintained on a broader basis than before. For mass was seen to represent concentrated energy.

The fact that mass represents concentrated energy became evident enough when the first atomic bomb exploded. In that explosion, a fraction of a body's mass was transformed into energy of motion of its constituent particles, killing one hundred thousand men, women and children.

Einstein's formula and the atomic bomb shattered the old idea that material particles are absolutely inert. The view that inertia is the sole distinguishing quality of matter could no longer be maintained, once it was seen that a particle's mass represents concentrated energy.

Moreover, there now emerged into full view the fact that so-called non-material fields exhibit – by reason of their energy content – the quality of inertia, measurable in terms of mass. The energy of a field represents 'diffused' mass; the mass of a

particle represents concentrated energy – this is the new concept which has emerged from relativity theory.

The demonstration that mass and energy are equivalent quantities led some scientists to imagine that matter is therefore a form of energy. Matter, wrote Jeans, 'becomes a form of energy'.* Matter and energy, according to H. Levy's *Modern Science*, 'are two opposites, a duality which in a wider sense than before we now call energy'.†

Such stale attempts to eliminate the concept of matter from the core of theoretical physics echo Duhem and Ostwald, who in the late nineteenth century endeavoured vainly to dissolve the concept of matter in the concept of energy.

The fact that mass and energy are equivalent does not mean that they are identical. The very use of different mathematical symbols for mass and energy indicates that these two physical quantities are not identical. We can appreciate the difference between mass and energy by realizing that they are both physical quantities, and that every physical quantity is a quantity *of something, or of some physical quality.*

Mass is quantity of inertia. Any unit of mass is a certain amount of the quality of inertia. Thanks to Newton, this much is generally understood. But energy, though admittedly a quantity, is not generally recognized to be a quantity of another quality – a physical quality dialectically opposed to inertia. Theoretical physics leaves unanswered the crucial question: what is energy?

Dialectic materialism provides the answer that physicists prefer to evade. If a somewhat lengthy quotation may be allowed from the second edition of the author's *Outlook of Science*, this answer runs as follows:

'Energy is presented in physics as a non-material "something" whose endless transformations underlie all physical processes; a non-material entity whose association with inert matter is responsible for physical change. Dialectic materialism lifts us above this creaking concept of inert matter and non-material energy. Modern materialists seek no cause external to matter in accounting for the motion of matter. Matter is self-motivated. Matter includes not only the quality of inertia, but also an

* J. Jeans, *The Universe around Us* (1933), p. 208.

† H. Levy, *Modern Science* (1939), p. 139.

opposite quality, measurements of which define quantities of energy.

Let us repeat at this point: a physical quality is a mode of existence or mode of behaviour of matter; that is, a tendency, or a state, or a form, or a process of the material universe. A physical measurement defines a............quantity or quantum of some physical quality. Quantities are defined numerically by adopting a particular quantity as a standard unit of measurement. The question is: what quality do we measure when we define energy numerically? Energy is admittedly a quantity. But a quantity *of what?*

Measurements defining energy numerically must be measurements of some *universal* quality. Since energy is an expression of actual or potential change, this universal quality must be a change-producing quality, opposite in character to the quality of inertia. To this measurable quality opposed to inertia, this universal tendency to physical change, we may apply the term *motivity,* whose dictionary definition is 'moving or impelling power'.

Quantity of motivity is energy. Energy is not an entity distinct from matter. Energy is the quantitative aspect of matter's general and inherent tendency to be active. The term energy was indeed coined by Thomas Young from the Greek word, ενεργός, meaning 'active'.

Motivity and inertia are two general modes of existence of matter. These two universal physical qualities interpenetrate one another to form a dialectic unity of opposites. When we measure motivity we define energy numerically. When we measure inertia we define mass numerically. The dialectic unity of motivity and inertia is expressed in the numerical equivalence of energy and mass, in accordance with Einstein's equation:

$$\mathrm{E} = mc^2$$

where E represents energy, m is mass, and c is a constant (the velocity of light *in vacuo*).

This equation may be written

$$\frac{\mathrm{E}}{m} = c^2$$

from which it is evident that the ratio of energy (quantity of

motivity) to mass (quantity of inertia) has a constant value, c being a numerical constant (3×10^{10}).

The numerical constant c, which is the ratio of the electromagnetic unit of charge to the electrostatic unit of charge, is the velocity of light *in vacuo*. Evidently the constancy of light's velocity is a quantitative expression of the dialectic relationship between motivity and inertia.

Energy, then, is the quantitative aspect of matter's motivity, just as mass is the quantitative aspect of matter's inertia. And motivity and inertia are two fundamental physical qualities – two dialectically opposed modes of behaviour of matter.

Together, motivity and inertia constitute a dialectic unity. There is no inertia without motivity; no motivity without inertia. In other words – quantitatively speaking – there is no mass without energy; no energy without mass.

If the motivity of a body increases in amount, as it does with the body's acceleration, there is a corresponding increase in the amount of the body's inertia. In other words, the body's mass increases with an increase of its kinetic energy. The ratio of the body's total energy to its total mass is thus maintained constant.

The ratio of energy to mass is also maintained constant when material particles are annihilated in the creation of radiating electromagnetic fields. This so-called annihilation of matter is actually a transformation of matter from one fundamental state to another – from the corporeal state to the incorporeal state. In this transformation of matter from one state to another, energy concentrated as the mass of particles becomes the comparatively diffuse energy quanta of electromagnetic fields.

In the reverse process, when electromagnetic fields are annihilated in the creation of particles (an electron and a positron) the energy of the fields becomes concentrated as the mass of the newly formed particles.

In each case, the constancy of the ratio of energy (E) to mass (m) is maintained, according to the equation

$$\frac{\mathrm{E}}{m} = c^2$$

where c is the velocity of light in *vacuo*.

While electromagnetic radiation is continuous as regards its wave structure of alternating fields, it is discontinuous as

regards its energy. The energy of electromagnetic radiation consists of discontinuous quantities of motivity, termed *photons.* Photons are not particles of matter; they are discontinuous quantities (quanta) of the motivity of matter.

Some phenomena, such as interference and polarization, reveal the continuous wave structure of radiating electromagnetic fields. Other phenomena, such as the photoelectric effect and the Compton effect, show the discontinuity of the energy of those fields.

An analogous case of combined continuity and discontinuity has been described by D. Gabor, with reference to 'acoustical "quanta" of human hearing'.*

A photon has not the indivisibility of an electron or other elementary particle of matter. Experiments show that waves of light whose energy is only *one* photon can pass through *two* holes in an opaque screen, and then produce an interference effect.

Only two explanations of this experimental fact are forthcoming. One is that the photon passed through only one hole in the screen, the light waves passing through the other hole having no energy. As this explanation is inconsistent with Maxwell's equations of electromagnetic radiation, the only alternative explanation is that one photon is so divisible as to pass through two holes in an opaque screen.

This divisibility of a photon does not apply to the emission or the absorption of radiant energy by material bodies. An atom cannot emit or absorb a quantum of radiant energy in two parts. That is to say, a photon is indivisible as regards energy *transformation.*

We come, then, to this conclusion, that energy is not an entity distinct from matter, but is the quantitative aspect of a fundamental quality of matter, namely motivity. This conclusion involves a radical revision of the basic premisses of physics, and a revolutionary change in the outlook of science.

Theoretical physics deals with four fundamental physical quantities – space, time, mass and energy. Physicists, however, fail to recognise that each of these is the quantitative aspect of a fundamental physical quality – a general mode of existence of matter.

* D. Gabor, *Nature*, May 3, 1947.

Space is the quantitative aspect of matter's extension. Time is the quantitative aspect of matter's motion. Mass is the quantitative aspect of matter's inertia. Energy is the quantitative aspect of matter's motivity.

The scientific method is based upon numerical definitions of physical quantities, made by means of measurements. Using this method with great success, physicists have been able to ignore the fundamental character of their own measurements. The theory of measurement has been the Cinderella of the sciences.

To transform this Cinderella into a radiant being, we have only to ask the question: if space, time, mass and energy are quantities, then quantities *of what?* Our answer to this question gives the theory of measurement its full value, and opens the way to vast new advances in all the sciences.

Every physical unit of measurement is a standard quantity of some physical quality – some mode of existence or mode of behaviour of matter. The gram, for instance, is a standard quantity of matter's inertia. The dyne is a standard quantity of matter's motivity – of matter's 'moving or impelling power', to give motivity its dictionary definition.

Motivity and inertia form a dialectic unit. This means that matter is active as well as passive; self-motivated as well as inert. This is the outstanding lesson to be learnt from the dialectics of nature.

Grasped intuitively by Diderot and other materialist thinkers, this great truth can now be expressed as a logical outcome of modern physics. As predicted by the American physicist, R. J. Oppenheimer, at a meeting of the American Physical Society in 1946, a fundamental revision of present theories of matter is coming, sponsored by the formidable facts of experimental physics.

There is coming, through recent advances in physics, a general recognition that matter is self-motivated. Matter has an endless capacity for self-change. This capacity is the quality we have termed motivity, the quantitative aspect of which is energy.

With the materialist understanding of nature which we have outlined, other sciences can become more closely co-ordinated with physics. Formulating further the quantitative relations of extension, motion, inertia and motivity, it will be possible to

grasp general laws of the behaviour and development of living physical systems, as well as non-living.

An immediate task of theoretical biology is to explore this possibility, so as to discover what determines the order and disorder, the stability and the instability, the growth and the senescence, of living organisms.

Embryology and the theory of evolution are ready to yield more secrets to biologists equipped with an understanding of modern materialism. While biologists have accumulated a vast wealth of factual information, biological theory lags far behind the theoretical development of physics. In particular, biology needs a comprehensive formulation of the law which evidently operates in opposition to the second law of thermodynamics.

According to thermodynamics, life is infinitely improbable! Hence the tentative search by a few biologists for some kind of field theory to account for the ordered development of living matter. In this search, our materialist principles point the way to new formulations. Life, it will be found, can be formulated fundamentally in terms of *specific forms* of extension, motion, inertia and motivity.

From our materialist standpoint, we see that matter tends spontaneously, of its own accord, towards order and organization, as well as towards disorder and disorganisation.

From atoms to stars, from amoebae to men, mutually opposing tendencies of matter operate in dialectic unity, producing ever different phases, states, stages and systems of physical change. Our senses enable us to picture perceptually some of the wonders of this ceaseless change.

The sciences show us the interplay of states, processes and tendencies that make up the complex flux of physical phenomena. Materialism helps us to glimpse as one great panorama of activity the many-sided magnificence of matter in motion.

Instead of the purely inert matter of theology and obsolete physics theory, we see matter in its rainbow raiment of self-motivated and creative activity. Like John Tyndall, we see in matter, 'hitherto covered with opprobrium, the promise and potency of every form and quality of life'.

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